Chapter 8
Significance of Information Technology

Highlights

Trends in IT

- **Information technology (IT) continues to develop and diffuse at a rapid rate.** Exponential quality improvements and cost reductions in microprocessors, storage, and networking are enabling new applications and the expanded use of IT.
- **The number of Internet hosts and servers continues to expand domestically and internationally.** In January 2001, more than 100 million computers were connected to the Internet.
- **The United States continues to be a leader in Internet access and use.** Internet use throughout the world is strongly dependent on telecommunication access charges.
- **Mobile phones are expected to be a major means of accessing the Internet in many countries.** The United States lags behind many other countries in mobile phone penetration. In June 1999, there were 28 mobile phones per 100 inhabitants in the United States compared with more than 60 per 100 inhabitants in Finland and Norway and 27 per 100 inhabitants in all Organisation for Economic Co-operation and Development (OECD) countries.

Societal Implications of IT

- **Businesses have invested heavily in IT.** Industry spending on IT equipment and software rose from less than $200 billion in 1993 to more than $600 billion in 2000.
- **Electronic commerce is having a major impact in traditional businesses.** Approximately 90 percent of electronic commerce (e-commerce) transactions are business to business rather than business to consumer. E-commerce is especially important in manufacturing, which has a history of pre-Internet e-commerce. E-commerce shipments accounted for 12 percent of the total value of manufacturing shipments, or $485 billion.
- **Retail e-commerce sales are still relatively modest.** The Census Bureau estimates 2000 retail e-commerce sales to be $27.3 billion.
- **Increasingly strong evidence suggests that IT is contributing to productivity and economic growth in the overall economy.** Productivity growth is especially evident in IT-producing sectors of the economy, but evidence of positive effects in IT-using sectors exists as well.
- **The Internet access gap between the richest and poorest areas of the world is large and, by some measures, still growing.** In 1997, Internet host penetration rates in North America were 267 times greater than rates in Africa; by October 2000, the gap had grown to a multiple of 540.
- **In the United States, Internet access is increasing for virtually all demographic groups.** The share of households with Internet access increased from 26.2 percent in December 1998 to 41.5 percent in August 2000.
- **Internet access remains greatest among people with the most income and education and is more common among Asian Americans and whites than blacks and Hispanics.** The share of black and Hispanic households with Internet access was about 18 percent lower than the national average. The growth rate in Internet access, however, was highest among these groups.
- **People with disabilities are only half as likely to have access to the Internet as people without disabilities.** IT may greatly aid people with disabilities by making work from home more viable and by providing aids to people with visual and hearing impairments.
- **Government is making increasing use of the Internet to provide constituent information and services and to conduct procurement and payment transactions.** Internet use is increasing at all levels of government. Interagency websites make it possible for government to organize services around segments of the population. State and local governments use the Web for a variety of services, such as issuing licenses, filing taxes, and applying for jobs.

Implications of IT for Science and Engineering

- **Modeling and simulation are becoming increasingly powerful complements to theory and experimentation in many areas of science and engineering.** The fastest supercomputers now run at more than 10 trillion operations per second. Modeling and simulation are increasingly used in a wide range of applications, including climate modeling, engineering design, and genomics.
- **Large, shared scientific databases have become key resources in many areas of science and social science.** Examples include gene and protein databanks, collections of satellite sensing data, and social science databases.
- **Electronic versions of journals, preprint servers, and other electronic resources are changing how researchers receive and disseminate technical information.** Research libraries are faced with competing demands for electronic and paper journals. Academic journals are facing challenges to their business models.

- **IT supports increased and larger scale research and development collaborations.** Many multi-institution projects now use advanced collaborative tools, Internet videoconferencing, remote access to scientific instruments, and shared databases.
- **IT has contributed to a market environment characterized by rapid innovation.** In most industries, companies know they must constantly innovate if they are to succeed in a market influenced by continuing improvements in IT.
- **IT affects the organization of innovation, within and among organizations.** IT can speed the flow of technical information within firms. It can also support innovation-related activities that are increasingly performed outside large firms by large and small companies that collaborate with each other and with academic institutions and government agencies.
- **Innovation in IT is accelerating and is different in some respects from innovation in other areas of technology.** IT patents' share of all U.S. patents increased from 9 percent in 1980 to 25 percent in 1999. IT patents cite other technology patents more extensively than scientific papers.
- **IT certificate courses are changing the way IT workers are trained.** Companies and associations have created more than 300 new certifications since 1989. Approximately 1.6 million individuals had earned about 2.4 million IT certificates by early 2000; half were earned by students outside the United States.
- **Use of IT in both traditional university courses and distance education continues to expand.** Many questions remain about the extent to which IT will change higher education.

Introduction

Information technology (IT) is a manifestation of public and private investment in science and engineering (S&E) that is enabling broad and significant changes in society. Many observers (Drucker 1999; Alberts and Papp 1997; Castells 1996; Freeman, Soete, and Efendioglu 1995; Kranzberg 1989) compare the rapid development and expansion of IT to the industrial revolution in terms of its potential scope and impact on society. Few other modern advances in technology have had the capacity to affect so fundamentally the way people work, live, learn, and govern themselves. As with the industrial revolution, both the time and direction of many of the changes are difficult to predict.

The relationship between IT and S&E has two aspects. In addition to being a product of S&E, IT is enabling changes in S&E. IT has become an important part of the overall U.S. investment in research and development (R&D) and affects how R&D is conducted in all disciplines. For example, scientists and engineers make extensive use of computer modeling and simulation and large shared databases; advances in networking facilitate global collaboration in research and product development; and IT producers employ scientists and engineers, implement the results of academic research, and conduct significant amounts of applied R&D. IT also influences the pipeline for S&E through its effects on the demand for people with technical skills and through its use in education at all levels.

This chapter addresses IT as a leading example of the effects of investment in S&E on society and focuses on IT as a major force underlying changes in the S&E enterprise.

A complete discussion of the impact of IT on society and the economy is beyond the scope of this chapter because IT has become integrated into nearly all aspects of society, from entertainment to national security. Moreover, in recent years, other government publications (Council of Economic Advisers 2001; U.S. Department of Commerce (DOC) 2000a,b) have begun to cover important aspects of the digital economy. References and notes in this chapter direct the reader to some of these other more detailed sources.

The chapter begins with a description of trends in IT and then discusses some major implications of IT, including effects on the economy and the general public. Finally, it discusses the effects of IT on elements of the S&E system, including R&D, innovation processes, higher education, and the IT workforce.

Trends in IT

IT, as defined in this chapter, reflects the combination of three key technologies: digital computing, data storage, and the ability to transmit digital signals through telecommunications networks. Rapid changes in semiconductor technology, information storage, and networking, combined with advances in software, have enabled new applications, cost reductions, and the widespread diffusion of IT. The expanding array of applications makes IT more useful and further fuels the expansion of IT.

Semiconductor Technology

Enormous improvements in the performance of integrated circuits and cost reductions brought about by rapid miniaturization have driven much of the advances in IT. See sidebar, “Moore’s Law.”

A related trend is the migration of computing into other devices and equipment. This is not a new trend—automobiles have been major users of microprocessors since the late 1970s—but as semiconductor chips become more powerful and less expensive, they are becoming increasingly ubiquitous. Also, new capabilities are being added to chips. These include microelectromechanical systems (MEMs), such as sensors and actuators, and digital signal processors that enable cost reductions and extend IT into new types of devices.[1] Examples of MEM devices include ink-jet printer cartridges, hard disk drive heads, accelerometers that deploy car airbags, and chemical and environmental sensors (Gulliksen 2000). Trends toward improvements in microelectronics and MEMs are expected to continue. See sidebar, “Nanoscale Electronics.”

Information Storage

Disk drives and other forms of information storage reflect similar improvements in cost and performance. (See figure 8-2.) As a consequence, the amount of information in digital form has expanded greatly. Estimates of the amount of original information (excluding copies and reproductions) suggest that information on disk drives now constitutes the majority of information (Lyman and Varian 2000). (See appendix table 8-2.) Increasingly, much of this information is available on-line.

Computers, reflecting the improvements in their components, have shown similar dramatic improvements in performance. Due to improvements in semiconductors, storage, and other components, price declines in computers (adjusted for quality) have actually accelerated since 1995. (See figure 8-3.)

Networking

The third trend is the growth of networks. Computers are increasingly connected in networks, including local area networks and wide area networks. Many early commercial computer networks, such as those used by automated teller machines and airline reservation systems, used proprietary systems that required specialized software or hardware (or both). Increasingly, organizations are using open-standard, Internet-based systems for networks.[2] As people have been

[1]Related terms are microstructure technologies or microsystem technologies (MSTs). To some, MSTs include all chips that have noncomputing functions (such as sensors or actuators), whereas MEMs are the subset of MSTs that have moving parts (Gulliksen 2000).

[2]The Internet, as defined by the Federal Networking Council, refers to the global information system that “(i) is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons; (ii) is able to support communications using the Transmission Control Protocol/Internet Protocol (TCP/IP) suite or its subsequent extensions/follow-ons and/or other IP-compatible protocols; and (iii) provides, uses, or makes accessible—either publicly or privately—high level services layered on the communications and related infrastructure described herein” (Kahn and Cerf 1999).

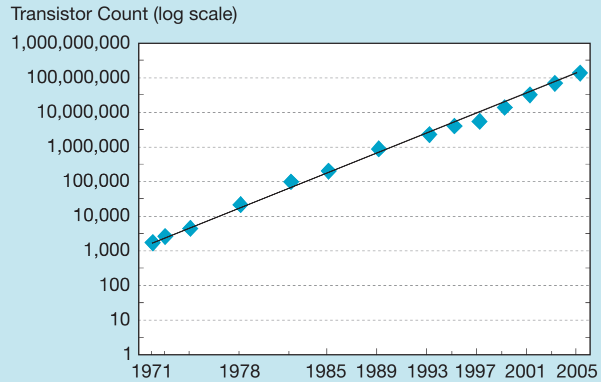
Moore's Law

The number of transistors on a chip has doubled approximately every 12 to 18 months for the past 30 years—a trend known as Moore's Law. (See figure 8-1 and appendix table 8-1.) This trend is named for Gordon Moore of Intel, who first observed it. Performance has increased along with the number of transistors per chip, while the cost of chips has remained generally stable. These factors have driven enormous improvements in the performance/cost ratio.

Moore's Law has become the basis for planning in the semiconductor industry. The International Technology Roadmap for Semiconductors (2000), a plan for semiconductor development prepared collaboratively by semiconductor industries around the world, is geared toward continuing improvements at approximately the rate predicted by Moore's Law.

Kurzweil (2001) suggests that this trend is not limited to semiconductors in the last few decades but that calculations per second per dollar have been increasing exponentially since electromechanical calculators were introduced in the early 1900s.

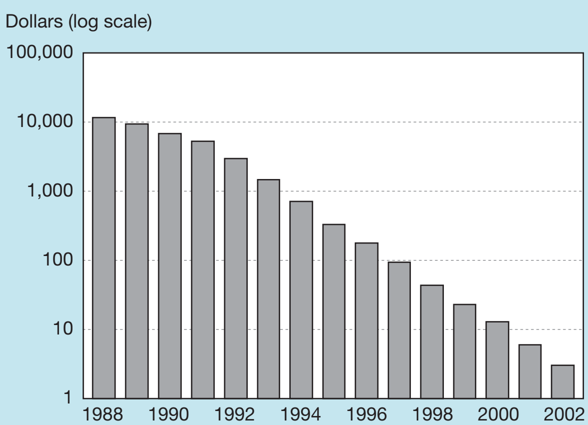
Figure 8-1.
Moore's Law: 1971–2005



NOTES: The line on the graph represents the trend that defines Moore's Law. The data points reflect actual (1971–2001) and projected (2003–2005) data.

See appendix table 8-1. *Science & Engineering Indicators – 2002*

Figure 8-2.
Cost per gigabyte of stored information: 1988–2002



NOTES: 2001 and 2002 data are projected.

SOURCE: P. Lyman and H. R. Varian. 2000. "How Much Information?" Available at <http://www.sims.berkeley.edu/how-much-info/>. Accessed July 2, 2001.

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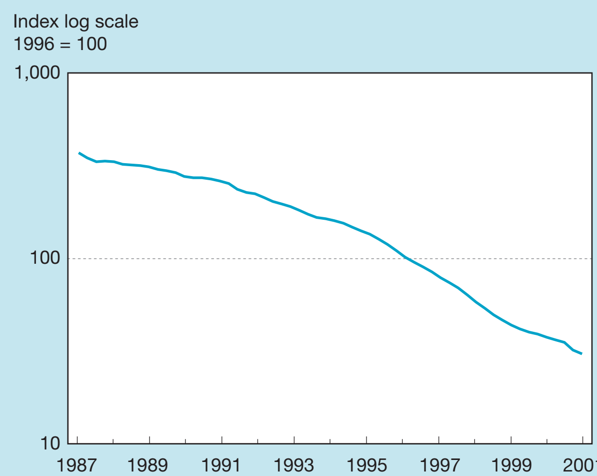
Figure 8-3.
Computer price declines



SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, National Accounts Data. Available at <http://www.bea.doc.gov/bea/dn1.htm>.

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able to interconnect and share information with each other, the value of IT has increased. See sidebar, "Metcalfe's Law."

The growth in networking has been enabled by rapid advances in optical networking. In 1990, a single optical fiber could transmit about 1 billion bits per second; by 2000, a single fiber could transmit nearly 1 trillion bits per second (Optoelectronics Industry Development Association 2001).

The growth in networking is best illustrated by the rapid growth of the Internet. Worldwide, there were nearly 100 million Internet hosts—computers connected to the Internet—in July 2000, up from about 30 million at the beginning of 1998. (See figure 8-4.) Networking is evolving in several ways: more people and devices are becoming connected to the network, the speed and capacity of connections are increasing, and more people are obtaining wireless connections. See sidebar, "Wireless Networking."

Applications of IT

A fourth trend is the ever-increasing array of applications that make IT more useful. Computers were originally used primarily for data processing. As they became more powerful and convenient, applications expanded. Word processing, spreadsheets, and database programs were among the early minicomputer and PC applications. Over the past two decades, innovations in software have enabled applications to expand to include educational software, desktop publishing, computer-aided design and manufacturing, games, modeling and simulation, networking and communications software, electronic mail, the World Wide Web, digital imaging and photography, audio and video applications, electronic commerce applications, groupware, file sharing, search engines, and many others. The growth and diversity of applications greatly increase the utility of IT, leading to its further expansion.

In the 1960s, computers were used primarily in the R&D community and in the offices of large companies and agencies. Over the past few decades, the expansion of applications has contributed to the rapid diffusion of IT to affect nearly everyone, not just the relatively few people in computer-intensive jobs. IT has become common in schools, libraries, homes, offices, and businesses. For example, corner grocery stores use IT for a variety of electronic transactions such as debit and credit payments, and automobile repair shops use IT to diagnose problems and search for parts from dealers. New IT applications are still developing rapidly; for example, instant messaging and peer-to-peer communication systems such as Napster are examples that have become popular in the past 2 years. See sidebar, "Peer-to-Peer Applications."

Societal Implications

In contrast to the steady and rapid advances in semiconductor technology, information storage, networking, and applications, the interaction of IT with various elements of society is more complex. Although IT performance in many cases improves exponentially, the utility to users in many cases improves more slowly (Chandra et al. 2000). For example, a doubling of computer processing speeds may bring only small improvements in the most widely used applications, such as word processing or spreadsheets. Furthermore, although it is common to talk about the "impact" or "effect" of IT or the Internet—implying a one-way influence—the interaction of IT with society is multidirectional and multidimensional. Over the past two decades, many studies have explored how organizations use IT. Cumulatively, these studies have found that a simple model of IT leading to social and organizational effects does not hold (Kling 2000). Instead, IT is developed and used in a social context in which organizations and individuals shape the technology and the way it is used. The implementation of IT is an ongoing social process that involves

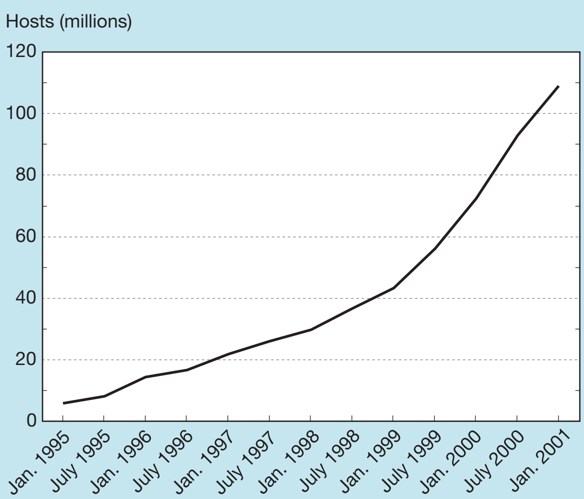
Nanoscale Electronics

As miniaturization proceeds, it may lead to the emergence of nanoscale devices (devices with structural features in the range of 1 to 100 nanometers). The International Technology Roadmap for Semiconductors (2000) projects semiconductor manufacturing to approximately 2010, at which time semiconductors are expected to have 0.1-micron (100-nanometer) structures. Beyond this, the principles, fabrication methods, and ways of integrating devices into systems are generally unknown. Potential applications of nanoscale electronics 10–15 years in the future include (National Science and Technology Council 2000):

- microprocessor devices that continue the trend toward lower energy use and cost per gate, thereby improving the efficacy of computers by a factor of millions;
- communications systems with higher transmission frequencies and more efficient use of the optical spectrum to provide at least 10 times more bandwidth, with consequences for business, education, entertainment, and defense;
- small mass storage devices with capacities at multiterabit levels, 1,000 times better than today; and
- integrated nanosensor systems capable of collecting, processing, and communicating massive amounts of data with minimal size, weight, and power consumption.

Such advances would continue to expand the cost effectiveness and utility of IT in new applications.

Figure 8-4.
Internet domain survey host count worldwide



SOURCE: Internet Software Consortium (<http://www.isc.org>).

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Metcalfe's Law

Metcalfe's Law states that the value of a network grows in proportion to the square of the number of users (Metcalfe 1996; and Downes, Mui, and Negroponte 1998). Just as the value of a telephone to a user depends on the number of other people who also have a telephone, the value of being on a computer network depends on how many other people are also on the network. As a network grows, its value to each individual user increases, and the total value of the network increases much faster than the number of users. This is also referred to as "network effects."

Technologies other than telecommunications also exhibit network effects. The value of owning a certain type of word processing software, for example, depends on how many other people use the same (or at least compatible) software to share files. A more widely used technology also becomes more valuable because more people are trained to use or service it. The more valuable a technology becomes, the more new users it will attract, increasing both its utility and the speed of its adoption by still more users.

Metcalfe's Law explains why the adoption of a technology often increases rapidly once a critical mass of users is reached and the technology becomes increasingly valuable. Because many technology developers are now aware of this phenomenon, initially they often heavily subsidize technologies that exhibit network potential to attain a critical mass of users. The Internet has been the most dramatic demonstration of Metcalfe's Law. Many Internet-related services also exhibit network effects, and many companies have heavily discounted their services in hopes of later being able to capitalize on the value of the network they have created.

The presence of network effects has implications for antitrust law. It implies that markets with strong network effects may tend toward monopoly, as the dominant technology becomes more valuable and the less widely used technology becomes less valuable (even if it is technically superior). It also may become more difficult for new entrants to become established if they need to compete with an established network.

changes in people's roles and in organizational procedures. Incentives and trust are important factors in the success of IT implementation. The following sections examine the effects of IT on the economy and the general public.

Economic Implications

Over the past two decades, there has been considerable debate over the extent to which IT is transforming the economy. Businesses have invested heavily in IT in anticipation of large productivity increases and economic transformations. Only recently, however, have economists found evidence of sector- or economywide IT-related productivity increases, and the question of whether the productivity gains are distributed across the economy or concentrated in the IT sector is still under debate (U.S. DOC 2000a; Council of Economic Advisers 2001).

Although topics such as the expansion of e-commerce and the stock market valuation of Internet companies have received much recent attention, these are only surface manifestations of the role of IT in the economy. This role is both broad and deep and involves changing the composition of the economy, changing productivity (primarily in traditional businesses), and changing both the nature of work and the needs of the workforce. This section outlines these changes.[3]

IT Applications in Business

Businesses have invested heavily in IT. The purchase of IT equipment continues to be the largest category of industry spending for all types of capital equipment (including industrial, transportation, and others). In current dollars, industry spending on IT equipment and software rose from less than $200 billion in 1993 to more than $600 billion in 2000. (See figure 8-7.)

Businesses use IT in many different ways. Some IT applications automate a variety of basic business activities, from production control systems in manufacturing to word processing and financial calculations in office work. Other applications involve databases and information retrieval that support management, customer service, logistics, product design, marketing, and competitive analysis. Through IT, companies can combine computing and communications to facilitate ordering and product tracking. IT functions often are implemented as mechanizations of older, manual processes; ideally, however, they involve fundamental redesign of processes. The use of IT by business began with and in many instances continues to rely on mainframe computers, minicomputers, and microcomputers, as well as telephone networks including the public switched network and leased-line private networks.[4]

More recently, the business community has begun to broaden integration of IT-based systems and, through them, integration of enterprises. The spread of Internet technology and the proliferation of portable computing and communications devices have accelerated trends that began in the past two decades and now are viewed as "electronic commerce" or e-commerce. Companies now use the World Wide Web to communicate with the general public and also use similar but more secure intranets and extranets to communicate with employees, suppliers, and distribution partners.

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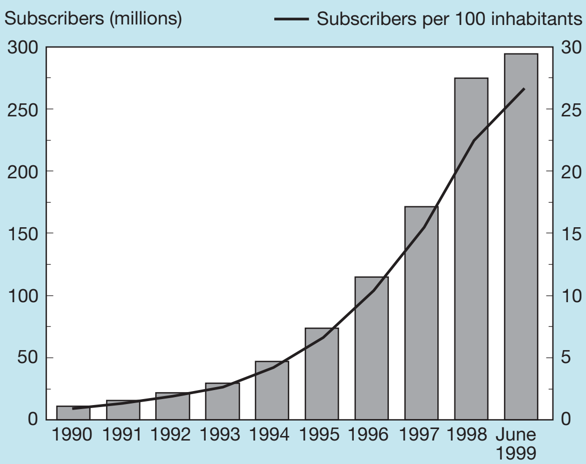
[3]A major U.S. Government source of information on IT and the economy is the *Digital Economy,* a series of reports published by the U.S. DOC's Economics and Statistics Administration. The 2001 edition of the *Economic Report of the President* (Council of Economic Advisers 2001) also focuses extensively on the role of IT in the economy.

[4]Businesses now also rely on virtual private networks, which use the open, distributed infrastructure of the Internet to transmit data between corporate sites, with encryption and other security measures to protect the data against eavesdropping and tampering by unauthorized parties.

Wireless Networking

At present, most people in the United States connect to the Internet through wires. Much of the growth in Internet connections, however, is expected to be through wireless connections. Currently, more people around the world have mobile phones than Internet access. Figure 8-5 shows the growth in mobile phone subscribers in Organisation for Economic Co-operation and Development (OECD) countries; figure 8-6 shows mobile phone penetration in individual OECD countries.

Figure 8-5.
Mobile phone subscriber growth in OECD countries: 1990–99



OECD = Organisation for Economic Co-operation and Development

See appendix table 8-3.

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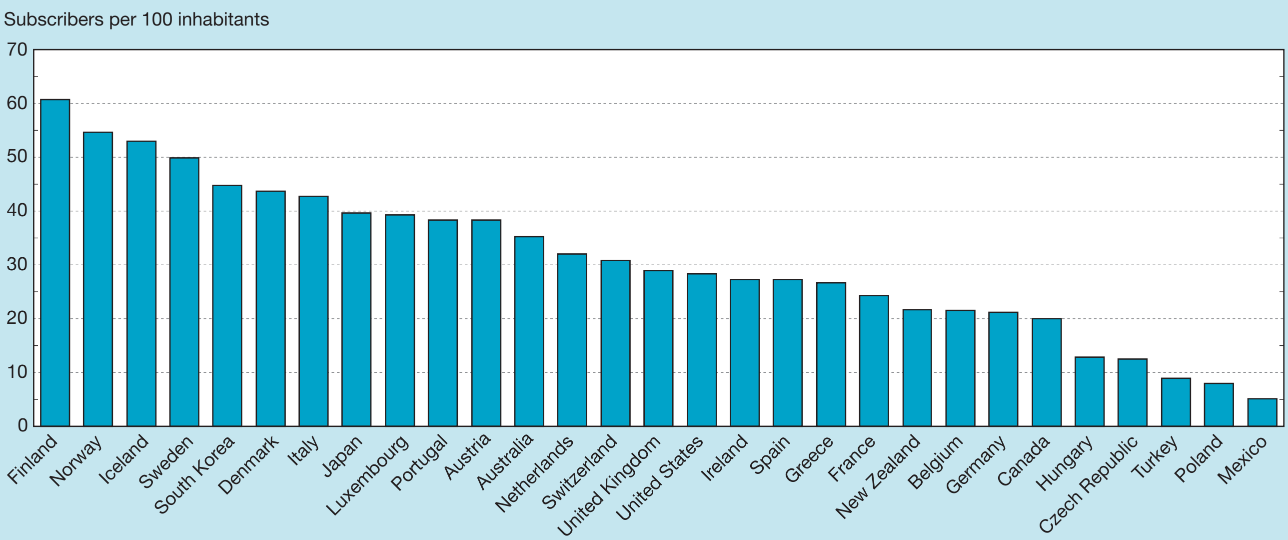
Over the next few years, most mobile phones will obtain Internet access (Wong and Jesty 2001). By 2005, the penetration level of mobile devices (including phones) with data capabilities is expected to approach mobile phone user penetration levels in the United States, Western Europe, and Japan. It is expected that, by then, all mobile terminals will be data enabled and subscribers will be able to access data and Internet services via mobile phones. As a result, it is likely that in many areas of the world where there are more mobile phone users than personal computer users, more people will have access to the Internet through mobile phones than through computers. International Data Corporation estimates that the number of wireless Internet subscribers in the United States, Western Europe, Asia/Pacific, and Japan will increase from 5 million in 1999 to more than 329 million by 2003 (Wrolstad 2001). Mobile Internet usage is growing particularly fast in Japan, primarily because of the popularity of the relatively low-cost NTT DoCoMo "I-mode" phones, which are being widely used for e-mail and games.

Because of the relatively small screen size, limited memory, and weak data entry capabilities of mobile phones, Internet access through mobile phones is qualitatively different from access through computers. Efforts are under way to determine what applications will work effectively over mobile phones. Successful mobile applications are likely to differ from typical computer-based applications. In addition to limited e-mail and Web browsing capabilities, mobile phones may also offer various location-based services, such as information on restaurants, shops, and services in the vicinity of the phone's current location.

Figure 8-6.
Mobile phone penetration in OECD countries: June 1999



OECD = Organisation for Economic Co-operation and Development

See appendix table 8-3.

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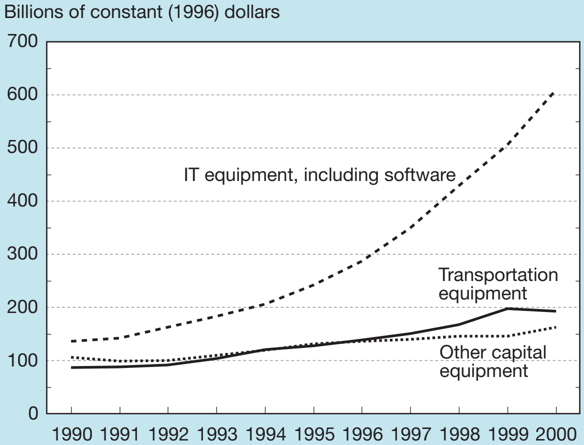
Figure 8-7.
Industry spending on capital equipment



SOURCE: Bureau of Economic Analysis. Available at http://www.bea.doc.gov/bea/dn/nipaweb/

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Peer-to-Peer Applications

A new class of applications known as peer-to-peer (P2P) services have become widely used. These applications take advantage of computing resources, such as storage, processing cycles, and content, available at the "edge" of the Internet, and include computers that are only temporarily connected to the Internet (Shirky 2000). In its early days, the Internet primarily connected computers at research institutions, and these computers shared resources on a fairly equal basis. Since the advent of the World Wide Web, the Internet has evolved into a client-server architecture, in which client computers connect to the Web primarily to download information. Many client computers are not permanently connected to the Web, do not have permanent Internet Protocol (IP) addresses, and thus are not available for other computers to access. P2P services provide a way for these computers to be available to others on the Internet.

The most widely known of the P2P services is Napster. Founded in 1999 by Shawn Fanning, then an 18-year-old college freshman, Napster enables users to find and access music files that are available on other users' computers. By March 2001, the Napster service had grown to the point where it was accessed by more than 4 million individual users each day (defined by unique IP addresses) and consistently had up to 500,000 concurrently active users (Napster 2001). Because Napster made it possible for people to share and copy copyrighted information, it has also raised some substantial intellectual property concerns. As a result of litigation, Napster has been required to remove copyrighted material from its network.

Many other less visible and less controversial P2P applications have been developed, including applications that let people access computer-based information across companies or government agencies, and applications that use idle computers to carry out complex scientific calculations (Ante, Borrus, and Hof 2001).

Growth of e-Commerce

The growth of e-commerce has changed the focus of the discussion of IT's role in the economy. Previously, the focus had been on how IT applications within companies could improve internal operations. With the growth of e-commerce, the focus has shifted to how businesses are using IT to communicate with customers and suppliers and develop new distribution chains and new methods of marketing and selling.

Definitions of e-commerce vary. The U.S. Census Bureau (Mesenbourg 2001) defines e-commerce as the value of goods and services sold on-line, with "on-line" including the use of the Internet, intranets, extranets, and proprietary networks that run systems such as electronic data interchange (EDI). Other definitions include only transactions that use open (generally Internet-based) systems rather than proprietary electronic systems.

E-commerce includes both business-to-business transactions and business-to-consumer transactions. The following sections summarize developments in these two areas.

Business-to-Business e-Commerce. Although business-to-consumer e-commerce has attracted more public attention, electronic transactions between businesses are much larger in volume. Because business-to-business e-commerce is built on the history of pre-Internet electronic transactions, many companies have substantial relevant expertise already in place. As a result, business-to-business e-commerce has expanded rapidly.

The U.S. Census Bureau (2001b) has produced estimates of 1999 e-commerce activity for several sectors of the economy. In manufacturing, e-commerce shipments accounted for 12.0 percent of the total value of shipments or $485 billion. For merchant wholesalers, e-commerce sales represented 5.3 percent of total sales or $134 billion. The Census Bureau estimates that approximately 90 percent of e-commerce transactions are business to business rather than business to consumer. The U.S. Census Bureau (2001b) also suggests that the manufacturing sector has a higher rate of e-commerce than other sectors because manufacturing firms (especially large ones) have been using private data networks for business-to-business transactions for many years.

Private estimates of business-to-business e-commerce in 2000 and 2004 are shown in text table 8-1. The private estimates vary in part because each firm uses somewhat different definitions. Despite the slowdown in the economy in 2001, many analysts still forecast continued growth for business-to-business e-commerce (Thompson 2001).

Business-to-business e-commerce enables businesses to offer their customers additional services and the means to improve communication. By improving communication, business-to-business e-commerce makes it possible for businesses to outsource more easily and to streamline and augment supply chain processes. It also allows businesses to eliminate

Text table 8-1.
U.S. business-to-business e-commerce estimates and forecasts: 2000 and 2004
(Billions of dollars)

Firm	Study date	2000	2004
Boston Consulting Group	September 2000	1,200	4,800
Forrester Research	February 2000	406	2,696
Gartner Group	March 2001	255	3,600
Giga Information	December 2000	957	3,804
International Data Corporation (IDC)	April 2001	117	1,000
Jupiter Research	September 2000	336	4,592
Yankee Group	April 2000	740	2,780

NOTE: Each firm listed defines business-to-business e-commerce differently.

SOURCE: *The Industry Standard*. Available at <http://www.thestandard.com/article/image/popup/0,1942,15847-15845-15846-15848,00.html>. Accessed August 19, 2001.

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some intermediary organizations between customers and suppliers but has also has given rise to new classes of business intermediaries, such as on-line auctions.

These new intermediaries can provide new places for buyers and sellers to meet, allow a variety of pricing schemes to flourish, alter the roles of traditional intermediaries, facilitate complex transactions, and shift the balance of power among market participants by making vast amounts of information available at very low costs (U.S. DOC 2000a). These on-line marketplaces enable buyers to solicit bids from a broader range of suppliers and allow suppliers to develop relationships with more buyers. In many cases, however, it is not yet clear how well these new intermediaries will work, in part because they do not replace certain functions such as the establishment of personal relationships based on trust found in traditional forms of business interaction.

The on-line marketplaces under development in the automotive industry exemplify this emerging form of business-to-business e-commerce. In February 2000, General Motors Corporation, Ford Motor Company, and Daimler Chrysler launched the e-business exchange Covisint in an attempt to consolidate their $600 billion in purchasing power, gain efficiencies, and lower costs (U.S. DOC 2000a). The Federal Trade Commission investigated the exchange because of antitrust concerns, and growth has been slower than expected (Welch 2001). The automobile industry has launched other exchanges similar to Covisint. In other examples, Sears, Roebuck and Company is joining with Carrefour SA, a Paris-based retailer, to create GlobalNetXchange, an on-line marketplace for the retail industry, and Boeing, Lockheed Martin, BAE Systems, and Raytheon Company plan to develop an Internet trading exchange for the global aerospace and defense industry (U.S. DOC 2000a).

Business-to-Consumer e-Commerce. Business-to-consumer (or retail) e-commerce has spawned many new businesses that have no physical stores but can deliver a wide variety of goods on request. In response, many traditional retail stores have launched their own e-commerce strategies.

Retail e-commerce sales are still modest. The U.S. Census Bureau (2001a) reported 2000 retail e-commerce sales to be $27.3 billion. In 1999, (the latest year for which detailed information is available) 76 percent of e-commerce sales were in North American Industry Classification System (NAICS) code 454110—Electronic Shopping and Mail-Order Houses. Text table 8-2 shows NAICS 454110 sales data by merchandise category. The two leading categories, computer hardware and books and magazines, account for approximately 50 percent of the NAICS 454110 total e-commerce sales.

The Census Bureau quarterly estimates of retail e-commerce sales are shown in figure 8-8. These estimates encompass sales of goods and services over the Internet, extranets, EDI networks, and other on-line systems. In these transactions, payment may or may not be made on-line. The figures include only retail firms and do not include on-line travel services, financial brokers and dealers, or ticket sales agencies, all of which are not classified as retail.

One mode of retail e-commerce that has expanded rapidly is the on-line auction, which puts buyers and sellers directly in touch with each other to negotiate a price. As of April 2001, eBay (one of the first and largest on-line auction enterprises) offered more than 5 million items for sale. During 2000, the value of goods traded on the eBay site was more than $5 billion (eBay 2001).[5] Hundreds of other on-line auction enterprises have been established, and many early e-commerce retailers such as Amazon.com and Dell Computer have added auctions as additional features of their websites.

IT Effects on Productivity and Economic Growth

As the IT sector has grown faster than the economy as a whole, its share of the economy has increased. (See figure 8-9.) IT also is commonly credited as being a key factor in the economy's structural shift from manufacturing to services. The widespread diffusion of IT is largely responsible for the growth in existing services (such as banking) and the creation of new service industries (such as software engineering) (Computer Science and Telecommunications Board (CSTB) 1994a; Link

[5]These sales are not captured in the Census Bureau figures, which only include sales from e-marketplaces that take title to the goods they sell. Generally, most e-marketplaces arrange for the purchase or sale of goods owned by others and do not take title to the goods they sell (U.S. Census Bureau 2001c).

Text table 8-2.
Electronic shopping and mail-order house total (NAICS 454110) and e-commerce sales by merchandise line: 1999

Merchandise Items	Sales (millions of dollars) Total	Sales (millions of dollars) E-commerce	E-commerce percentage of total sales	Percent distribution E-commerce	Percent distribution Total
Total sales	93,149	11,733	12.6	100.0	100.0
Books and magazines	3,611	1,631	45.2	13.9	3.9
Clothing and clothing accessories (including footwear)	12,363	757	6.1	6.5	13.3
Computer hardware	25,098	4,336	17.3	37.0	26.9
Computer software	2,484	760	30.6	6.5	2.7
Drugs, health aids, and beauty aids	10,362	258	2.5	2.2	11.1
Electronics and appliances	2,258	399	17.7	3.4	2.4
Food, beer, and wine	1,540	230	14.9	2.0	1.7
Furniture and home furnishings	5,494	240	4.4	2.0	5.9
Music and videos	4,490	809	18.0	6.9	4.8
Office equipment and supplies	7,502	600	8.0	5.1	8.1
Toys, hobby goods, and games	2,052	391	19.1	3.3	2.2
Other merchandise[a]	14,723	966	6.6	8.2	15.8
Nonmerchandise receipts[b]	1,173	356	30.3	3.0	1.3

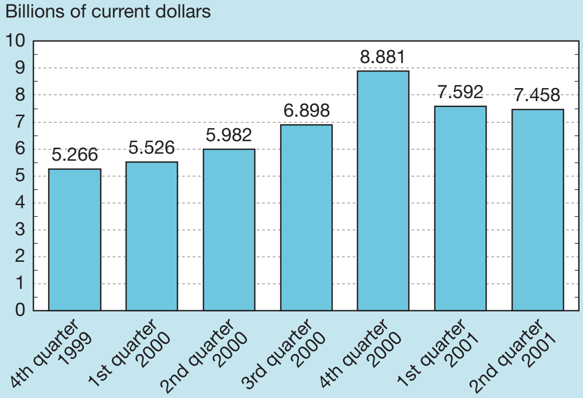
[a]Merchandise such as jewelry, sporting goods, collectibles, souvenirs, auto parts and accessories, hardware, and lawn and garden supplies.

[b]For example, auction commissions, shipping and handling, customer support, and online advertising.

NOTES: Details may not add to totals because of rounding. Data are grouped according to merchandise categories used in the *Annual Retail Trade Survey.* North American Industrial Classification System (NAICS) 454110, "Electronic shopping and mail-order houses" comprises businesses primarily engaged in retailing all types of merchandise through catalogs, television, and the Internet. Data are preliminary and subject to revision.

SOURCE: U.S. Bureau of the Census. *1999 Annual Retail Trade Survey.* *Science & Engineering Indicators – 2002*

Figure 8-8.
Estimated quarterly U.S. retail e-commerce sales: 4th quarter 1999–2nd quarter 2001



NOTE: Data are not adjusted for seasonal, holiday, or trading day differences.

SOURCE: U.S. Department of Commerce. Available at <http://www.census.gov/mrts/www/current.html>

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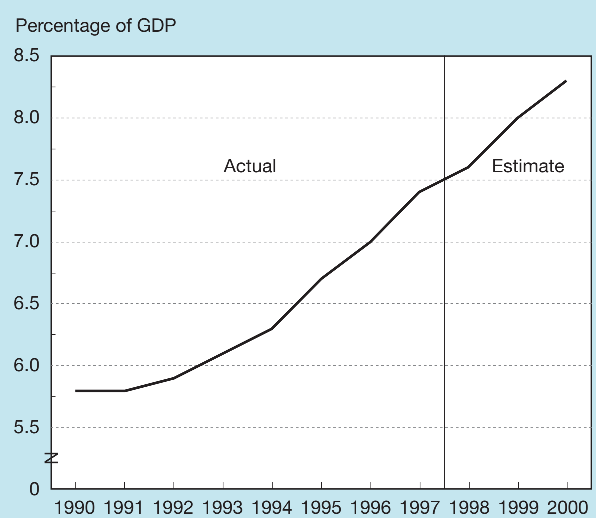
Figure 8-9.
Economy share of IT-producing industries



GDP = gross domestic product

SOURCE: U.S. Department of Commerce, Economics and Statistics Administration, 2000. *Digital Economy 2000*. Washington, DC.

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and Scott 1998). In addition to its role in changing the structure of the economy, IT affects productivity and economic growth overall, as discussed in the following sections.

The Productivity Paradox: Recent Studies. For a long time, little evidence showed that IT had improved productivity in the aggregate. Solow (1987) noted that "we see computers everywhere but in the productivity statistics," an observation that became referred to as the "productivity paradox." Many econometric analyses failed to find any sector- or economywide productivity benefits for IT (for reviews of this literature, see Brynjolfsson and Yang 1996 and CSTB 1994a).

Several explanations have been put forward for the productivity paradox. One explanation involves measurement difficulties. Much of the expected effect of IT would occur in the service industries, where productivity is always difficult to measure. IT may lead to improvements in services that do not readily show up as productivity improvements. Another possibility is that productivity has not increased in the aggregate because it takes time and investment in training for organizations to learn to use IT effectively. Using IT is expensive not only in terms of initial costs but also in terms of the cost to maintain and upgrade systems, train people, and make the organizational changes required for a company to benefit from IT. Such costs may greatly exceed the original investment in IT equipment. Although some companies have successfully made these investments and have greatly benefited, many have not. Another possible explanation is that until the 1990s, business investment in IT was small enough that one would not expect to see a large productivity increase in the overall economy.

In the past few years, however, several studies that have used a variety of approaches have concluded that IT is having a positive effect on productivity (U.S. DOC 2000a; Council of Economic Advisers 2001). Economists who were skeptical about the impact of computers on U.S. productivity have begun to credit IT for increases in the growth rates of output and productivity since 1995. Several studies found that the acceleration in productivity growth during the mid-1990s was attributable largely to increased computer use (capital deepening) among IT users and also to technical advances and innovations by IT producers (U.S. DOC 2000a).

Sector-level studies also suggest that IT investments contribute to productivity growth. U.S. DOC (2000a) found that IT-intensive goods-producing industries have achieved higher productivity gains than their non-IT-intensive counterparts but that the effect of IT on service industry productivity will remain clouded until better output measures are developed.

Recent firm-level analyses also have shown that IT contributes substantially to productivity growth. Brynjolfsson and Hitt (2000, 1998, 1996, 1995) have explored the relationship between computers and productivity growth at the firm level and have found positive correlations between IT and productivity. They also have found that investments in organizational change greatly increase IT's contribution to productivity. Brynjolfsson and Hitt (1998) conclude that although computerization does not automatically increase productivity, it is an essential component of a broader system of organizational change that does.

Inflation and Overall Economic Growth. IT appears to be having positive effects on inflation and growth. These effects derive primarily from price and growth trends in the IT sector rather than from IT applications in other sectors. U.S. DOC (1999a, 2000a) found that declining prices in IT-producing industries have helped to reduce inflation in the economy as a whole. Declining IT costs may also have helped other industries to control their costs. DOC also found that IT-producing industries have contributed substantially to overall economic growth, accounting for more than one-third of the growth in real output between 1995 and 1999.

Outlook for Continued Productivity Growth. Litan and Rivlin (2001) estimated how much the Internet might contribute to productivity increases in the future. In their study, experts in particular sectors of the economy examined how the Internet was being used in leading firms or institutions in these sectors; what the impact on cost, prices, and productivity appeared to be; and how rapidly the Internet's impact might spread to other parts of the sector. See sidebars, "The Internet and Productivity in the Automobile Industry" and "The Internet and Productivity in the Personal Computer Industry." Based on these sector analyses, Litan and Rivlin concluded that the Internet has the potential to add as much as 0.2–0.4 percent a year to productivity. The improvements result from the application of networked computing via the

The Internet and Productivity in the Automobile Industry

The Internet can potentially lead to cost reductions and productivity improvements in the automobile industry in a variety of ways (Fine and Raff 2001). Potential savings can occur in:

- product development (improved ease of making engineering changes, reduced cost of making changes, lower direct cost of communication and coordination, faster product development cycle speed);
- procurement and supply (reduced transaction costs in purchasing, more bulk buying and shipping, more price competition among suppliers, improved logistics and reduced "rush" orders as a result of better information);
- manufacturing system (improved design for ease of manufacture, faster setups, smaller lot sizes, reduced inventory, higher capacity utilization, more outsourcing); and
- vehicle order-to-delivery management (reduced order-to-delivery cycle times, lower inventory levels in pipeline, better matching of supply to demand, less discounting of undesired stock, lower sales commissions, fewer dealers and lower total overhead, fewer distribution centers, and lower shipping costs).

The estimated combined potential for cost reductions in these areas is equivalent to 13 percent of the cost of automobiles. Achieving these savings, however, would require changes in the manufacturing system and supply chain that would be difficult to bring about, and actual cost saving may be much lower. Nevertheless, because the automobile industry is large, achieving only part of these savings could result in measurable productivity changes in the overall economy.

The Internet and Productivity in the Personal Computer Industry*

The personal computer (PC) industry has been closely linked to development of the Internet. The availability of inexpensive PCs has fueled expansion of the Internet, and the Internet, in turn, has driven much of the demand for PCs. It is not surprising that the PC industry has been an early adopter of the Internet as a business tool.

Cutthroat pricing, rapid technological change, global supply and distribution chains, and changing consumer tastes have characterized the PC industry. The modularity of PCs and the availability of components on the open market have led to intense competition at many levels in the industry. No single business and distribution model has dominated the industry, which includes large global players such as Compaq, Hewlett-Packard, and IBM that sell through traditional distribution channels, direct-order marketers such as Dell, and many small companies.

As a strategy for meeting the intense price competition in the PC industry, some manufacturers began to use foreign sources for components and even for finished PCs. However, this tended to lead to having more components tied up in the supply and distribution chain for a longer time. Constant improvements in the cost and performance of semiconductors and disk drives (see figures 8-1 and 8-2) have led to continued and even accelerating improvements in the cost and performance of computers (see figure 8-3). The effect of the price declines of PCs has meant that components and computers depreciate very quickly. In this environment, improving efficiency throughout the supply chain—from component producer to consumer—is extremely important.

The direct-order process whereby customers order computers directly from the manufacturer has great advantages in this respect. Dell, for example, builds its PCs only after they are sold to the consumer, thereby greatly reducing the inventory and risks associated with price reductions and changing consumer tastes. Making the supply chain more efficient became more important as technical change and price reductions accelerated. By 1996–97, the traditional assembly-to-distribution channel marketing system was at a competitive disadvantage to the direct-order marketing model.

The Internet reinforced the competitiveness of direct marketers and increased difficulties for traditional assemblers. It allowed direct marketers to provide better support than was possible through traditional catalog and telephone service. Companies first put technical support information on-line, then let customers configure and price PCs on-line, and finally made it possible for customers to conduct entire transactions on-line. For direct marketers, replacing telephone operators (who were simply conduits for entering orders into a computer) with an Internet-based interface did not represent a great change in technical and business strategy and allowed Internet-based sales to grow quickly.

At Dell, for example, Internet-based sales grew from $1 million per day in December 1996 to $40 million per day by February 2000, equal to 50 percent of total sales. Dell also achieved substantial savings through Internet-based sales transactions. For example, the company estimated that it saved more than $21 million through avoided order status calls in 1999. The Internet also permitted Dell to increase service to its corporate customers and improve communication with its largest suppliers, allowing them to use the Internet to find out Dell's requirements for incoming materials, receive statistics from the company's manufacturing lines, and gather data on the reliability of components supplied.

Traditional computer makers have attempted to emulate aspects of the Internet-based direct-order marketing model. Most have either been slower to implement the model or unable to implement it fully because the model puts them in direct competition with their traditional distribution chains.

Several new startup companies have formed to sell PCs from their websites or to refer customers to assemblers or distributors. Many of the startups, however, have experienced difficulty making a profit, in part because established PC companies were quick to implement Web-based sales and other activities. The startups have added an additional marketing channel but have not transformed the PC industry. The main effect of the Internet on the industry appears to have been the strengthening of the direct-order marketing business model.

*The source for material in this section, unless otherwise noted, is Kenney and Curry (2000).

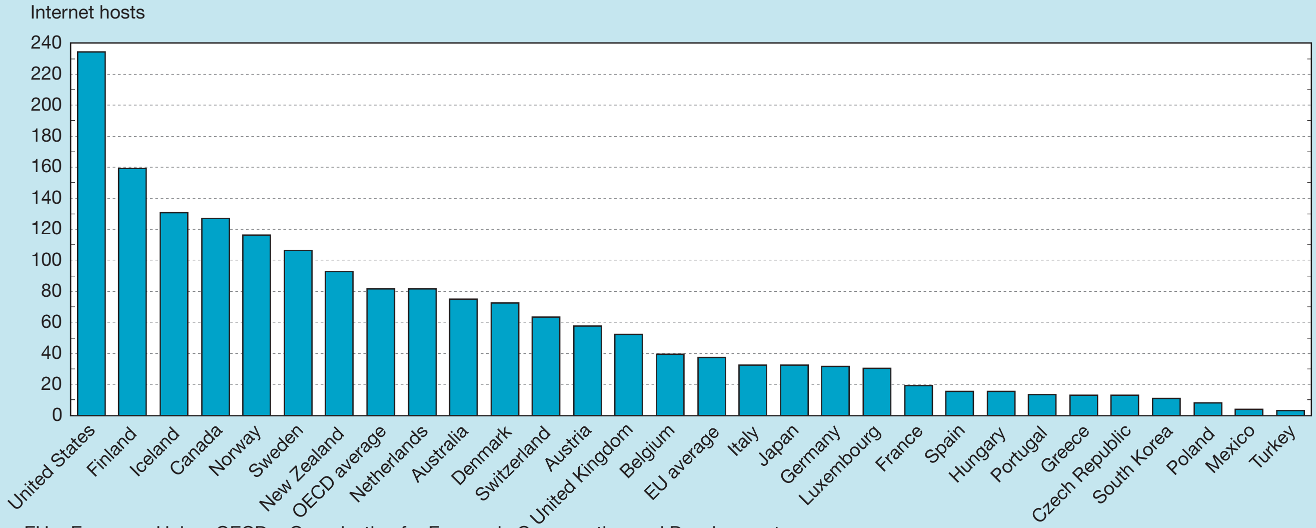
Internet and intranets to business activities carried out in companies devoted to such "old economy" activities as manufacturing, transportation, financial services, and conventional retailing. Major cost savings resulting from Internet use in the government and health sectors also are likely to contribute to overall productivity growth.

IT Effects on Income and Work

IT both creates and eliminates jobs. As jobs are created or eliminated, labor markets adjust in complex ways. Wages go up in areas (occupations or locales) in which the demand for skills exceeds the supply and go down in areas in which there are more jobs than workers. Over time, the effects of IT are likely to appear not in unemployment figures but in the wages of different occupations.

As noted by Katz (2000) in a review of the literature on computerization and wages, many studies have found that education-based wage differentials have increased in the past two decades, coinciding with the computerization of the workplace. The increases in both the wages and relative supply of

Figure 8-10.
Internet hosts, per 1,000 inhabitants in the OECD countries: October 2000



EU = European Union; OECD = Organisation for Economic Co-operation and Development

See appendix table 8-4.

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educated workers are consistent with the idea that IT allows skilled workers to perform more functions and produce things that previously were in the domain of less skilled workers. This diminishes the "terms of trade" of less skilled workers, thereby reducing their relative income (Johnson and Stafford 1998; Gomery 1994).

Katz (2000) notes that within industries, relative increases in employment and wages during the 1980s and 1990s were greater for workers with more education, an indication of labor market shifts favoring workers with more skills. He also found that skill-related and organizational changes that have accompanied the computer revolution appear to have contributed to faster growth (starting in the 1970s) in the demand for skilled labor. However, factors other than technological change, including a slowdown in the increase of college-educated people entering the labor force, a trend toward globalization (especially outsourcing of low-skilled work to other countries), and a weakening of labor unions, may also contribute to rising wage differentials.

Many people have feared that automation will reduce demands on workers' conceptual talents and facility with machinery, equipment, and tools. On the other hand, IT can be expected to increase the demand for "knowledge workers" (those who manipulate and analyze information) relative to the demand for workers who do not process information as part of their jobs or those who simply enter and collate data. Case studies of specific industries, occupations, and IT show that IT can in some cases increase and in other cases reduce the level of skill required in particular jobs. (For reviews of such studies, see Attewell and Rule 1994, Cyert and Mowery 1987.) On balance, however, several studies (Autor, Katz, and Krueger 1997; Castells 1996; Berman, Bound, and Griliches 1994; Howell and Wolff 1993) using different data sets and methodologies suggest that no overall deterioration of skills is occurring in the workforce and that upgrading of skills may be widespread.

IT and the Citizenry

IT is part of the fabric of daily life, supporting activities at home, work, and school. This section addresses how IT affects citizens and society. It focuses on three areas: participation in the digital economy, IT applications in the home, and the influence of IT on government's interaction with its citizenry.

Participation in the Digital Economy

The past few years have seen widespread concern that digital technologies may be exacerbating existing differences in demographic groups' access to information and, consequently, their ability to participate fully in the information society. The term "digital divide" has been widely used to characterize demographic gaps in effective use of IT. This section begins with a brief summary of Internet access indicators worldwide. It also examines recent data on access to and use of IT (primarily the Internet) by different demographic groups in the United States, including comparisons by income, education, and race/ethnicity. Finally, it looks at Internet access among people with disabilities, reasons people do not use the Internet, and new modes of accessing the Internet.

Global Internet Access. Text table 8-3 shows the growth in Internet hosts in different areas of the world. Although rapid growth continues in much of the world, the international digital divide is still significant, and Africa appears to be falling farther behind. In October 1997, Internet host penetration in North America was 267 times that in Africa; by October 2000, the gap had grown to a multiple of 540.

A wide variation in Internet hosts per 1,000 inhabitants also exists among OECD countries. As shown in figure 8-10 and appendix table 8-4, the United States and Scandinavian countries lead, while such large economies as Germany, Japan, and France are significantly below the OECD average.

A major factor affecting Internet use across countries is telecommunications access charges. As shown in figure 8-11, a

Text table 8-3.
Internet hosts, per 1,000 inhabitants: trends by world region

Region	October 1997	October 1998	October 1999	October 2000
North America	46.28	69.74	116.41	168.68
Oceania	26.81	34.76	43.84	59.16
Europe	6.13	9.45	13.41	20.22
Central and South America	0.48	0.91	1.67	2.53
Asia	0.53	0.87	1.28	1.96
Africa	0.17	0.21	0.28	0.31

SOURCE: Organisation for Economic Co-operation and Development (OECD). 2001. *Understanding the Digital Divide.* Paris. Available at <http://www.oecd.org/dsti/sti/prod/Digital_divide.pdf>.

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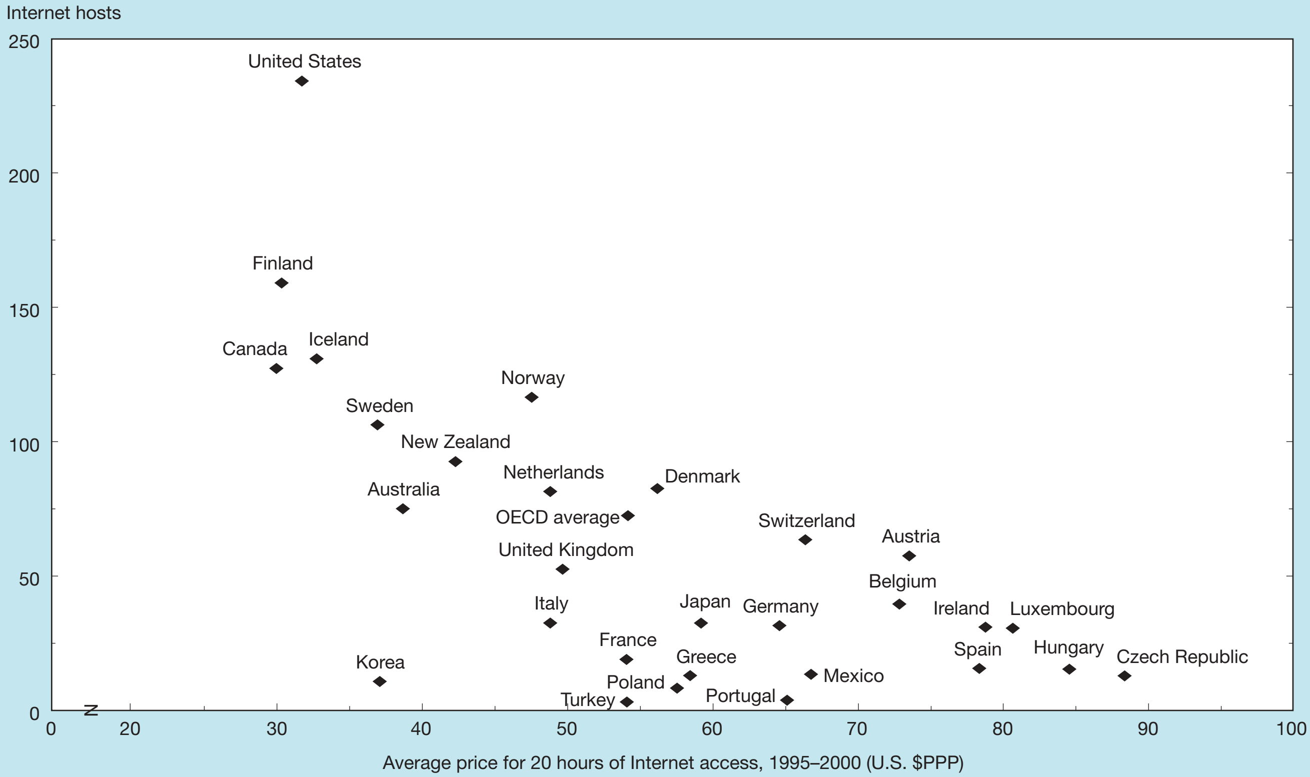
Figure 8-11.
Internet access prices and Internet host penetration per 1,000 inhabitants: October 2000



OECD = Organisation for Economic Co-operation and Development; PPP = purchasing power parity

NOTES: Data on hosts for Luxembourg are from mid-1999. Internet access costs include value-added taxes.

SOURCE: OECD (www.oecd.org/dsti/sti/it/cm) and Telcordia Technologies (http://www.netsizer.com)

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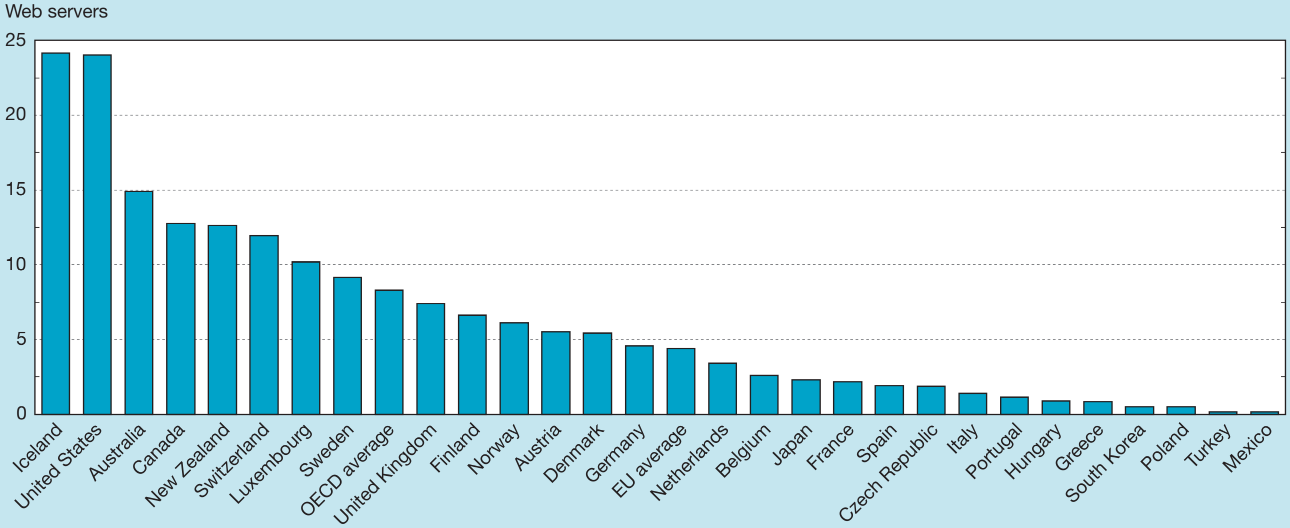
strong correlation exists between the price of Internet access and the number of Internet hosts per 1,000 inhabitants.

Because secure Web servers (those that use encryption and third-party certification) are needed for electronic transactions in both commerce and government, their number and locations are key indicators of the use of networks for business purposes. Figure 8-12 shows the number of secure Web servers per 1 million inhabitants in OECD countries as of July 2000. The United States currently leads by this measure, but servers suitable for e-commerce are dispersing around the globe. As of July 2000, more than 96,000 secure servers were operating in OECD countries—more than four times as many as in July 1998.

Indicators of Participation in the Digital Economy. In the 1980s, households that had PCs were on the cutting edge of IT use; since the mid-1990s, however, access to the Internet has become the primary indicator of a household's IT use. Because the Internet opens information resources to people in ways that unconnected PCs do not, this section emphasizes Internet access more than computer ownership.

In the future, many people may achieve Internet access through interactive televisions, personal digital assistants, and

Figure 8-12.
Secure Web servers per 100,000 inhabitants in OECD countries: July 2000



EU = European Union; OECD = Organisation for Economic Co-operation and Development

SOURCE: Organisation for Economic Co-operation and Development. *Communications Outlook – 2001*. Paris. 2001. Based on data from Netcraft. <http://www.netcraft.com>.

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wireless telephones. However, these technologies may provide considerably less access to information resources than is possible through a computer. Internet access alone ultimately may not be the key measure of ability to participate in the digital economy. It may be necessary to examine the quality of Internet access and how that access is used.

Physical access to technology is not enough to ensure participation in the digital economy (Wilson 2000). People need the kind of educational background that will prepare them to use the technology effectively to find and access information. They also need to be able to process and evaluate the information they find. In addition, the information content must be of use to them; for example, if the Internet offers little content in a person's language, then Internet access offers little benefit to that person.

Research on Home IT Diffusion. The research literature on technological diffusion shows that individuals who are affluent, better educated, and employed in higher status occupations (compared with society as a whole) tend to be early adopters of new technologies. This pattern holds true for all kinds of household products, technologies, and innovations, including PCs and Internet access. Research conducted in the 1980s and 1990s on home IT diffusion found that income and other socioeconomic factors such as education were strong predictors of early PC use (McQuarrie 1989; Dutton, Rogers, and Jun 1987; Riccobono 1986; Dickerson and Gentry 1983). Hoffman and Novak (1998) found complex relationships between home IT access (as measured by ownership of PCs) and race, income, and education. They found gaps in computer ownership that could not be accounted for by differences in income or education. When they controlled for education, they found statistically significant differences in computer ownership between blacks and whites.

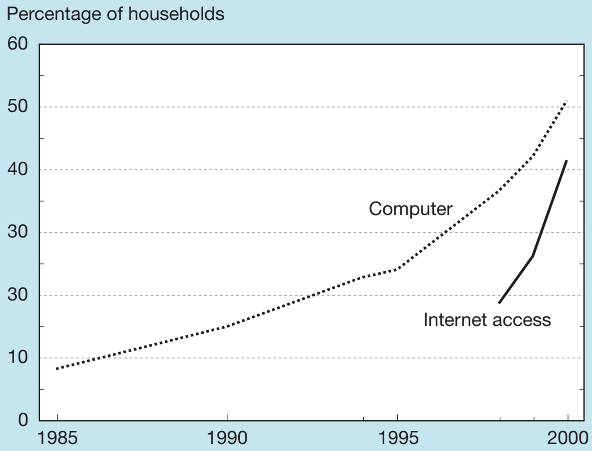
Computer and Internet Access: Recent Data From the Census Bureau's Current Population Survey. Recent data on computer and Internet access, collected by the Census Bureau in a supplement to its August 2000 Current Population Survey (CPS) (U.S. DOC 2000b), are consistent with the research literature. Because CPS is a very large survey (48,000 interviewed) and puts a heavy emphasis on quality, it provides a very reliable measure of computer and Internet access. The survey gathers information on both entire households and individuals within households.[6] Data from similar previous surveys (most recently, December 1998) can be used to identify trends in computer and Internet access.

- ♦ ***Overall Trends.*** CPS data show that as of August 2000, more than half of all households (51.0 percent) had computers, up from 42.1 percent in December 1998. (See figure 8-13 and appendix table 8-5.) The share of households with Internet access increased from 26.2 percent in December 1998 to 41.5 percent in August 2000. As of August 2000, 116.5 million Americans were on-line at some location, 31.9 million more than were on-line only 20 months earlier. (See appendix table 8-6.) The share of individuals 3 years or older using the Internet rose by one-third, from 32.7 percent in December 1998 to 44.4 percent in August 2000. (See appendix table 8-7.)

Although Internet access varies by income, education, race/ethnicity, age, and location, access has been increasing across all of these groups.

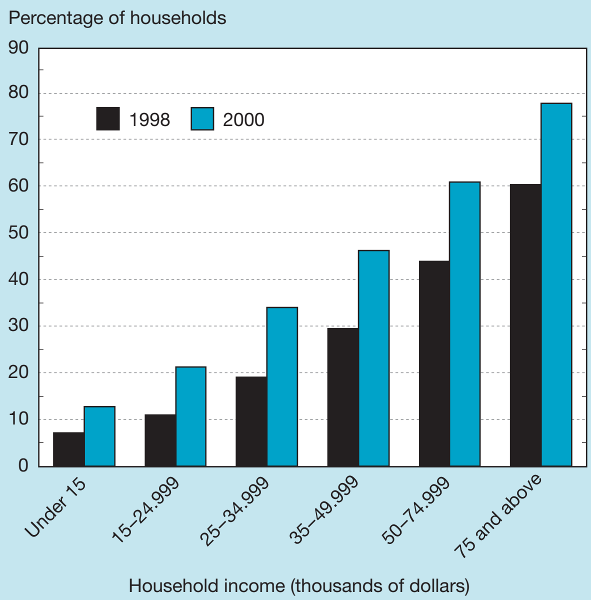
[6] The August 2000 survey gathered information on a total of 121,745 individuals, including children.

Figure 8-13.
U.S. households with a computer and with Internet access



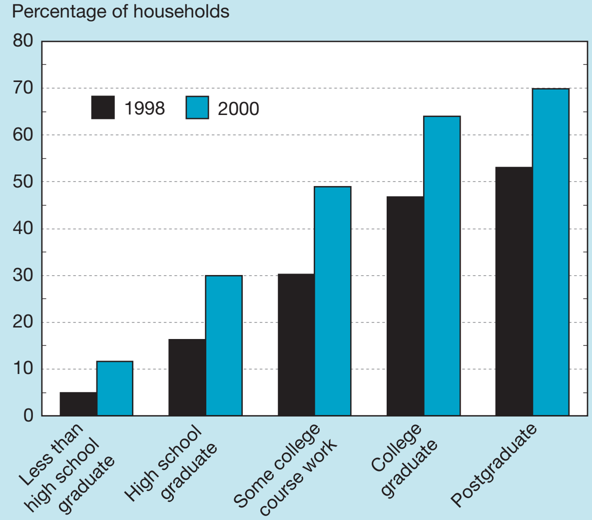
See appendix table 8-5. *Science & Engineering Indicators – 2002*

Figure 8-14.
U.S. households with Internet access, by income: 1998 and 2000



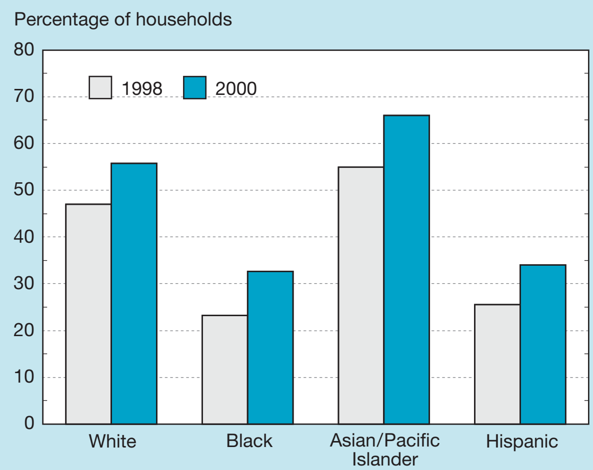
See appendix table 8-6. *Science & Engineering Indicators – 2002*

Figure 8-15.
U.S. households with Internet access by educational attainment of householder: 1998 and 2000



See appendix table 8-6. *Science & Engineering Indicators – 2002*

Figure 8-16.
U.S. households with a computer, by race/ethnicity: 1998 and 2000



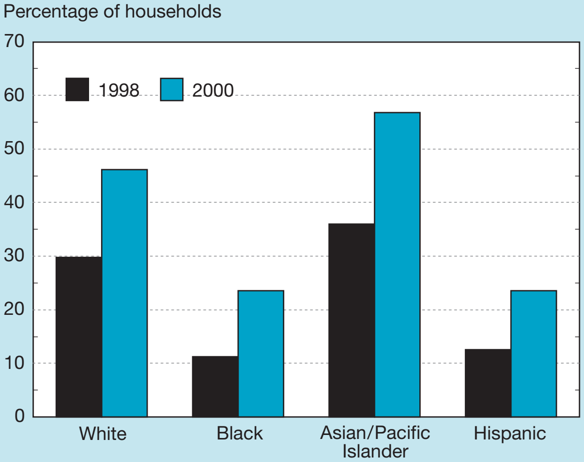
See appendix table 8-5. *Science & Engineering Indicators – 2002*

♦ ***Income.*** Figure 8-14 shows the number of households with Internet access, by income level, as of December 1998 and August 2000. It remains highest among households with the highest income, but people at every income level are increasing Internet access at home. More than two-thirds of all households that earn more than $50,000 have Internet connections.

♦ ***Education***. Similarly, although people with the highest level of education are most likely to have Internet access, access is also expanding across every education level. (See figure 8-15.)

♦ ***Race/Ethnicity.*** As shown in figures 8-16 and 8-17, blacks and Hispanics continue to lag significantly behind whites and Asians/Pacific Islanders in both computer ownership and Internet access. In August 2000, the share of black households that owned computers was 18 percentage points below the national average (32.6 percent for black households compared with 51.0 percent for all households nationally). Similarly, the share of Hispanic households with a computer (33.7 percent) was 17 percentage points below the national average. The share of black and Hispanic households with Internet access was also approximately 18 per-

Figure 8-17.
U.S. households with Internet access, by race/ethnicity: 1998 and 2000



See appendix table 8-6. *Science & Engineering Indicators – 2002*

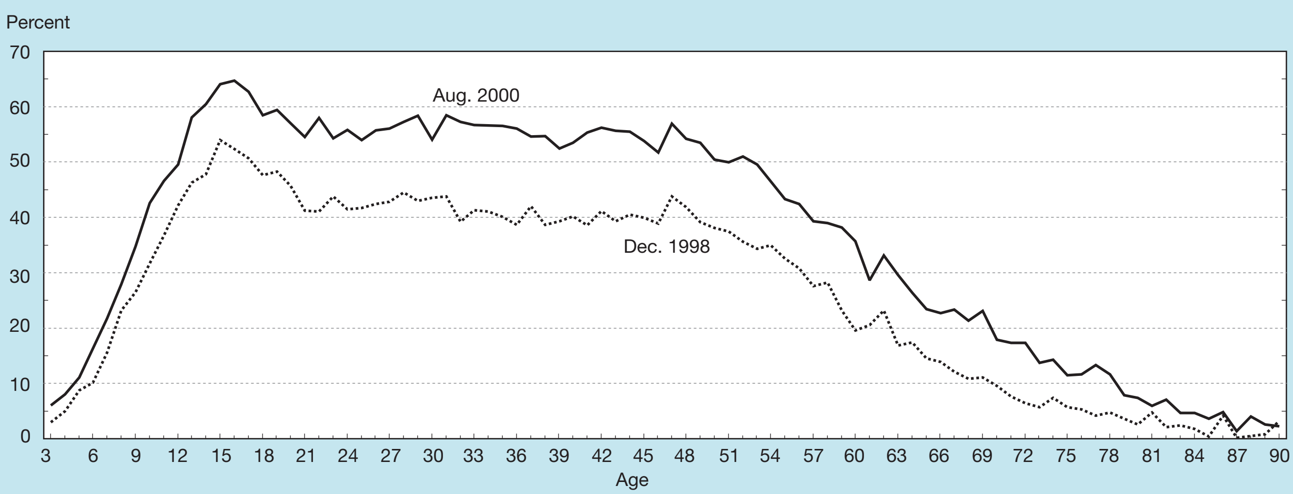
centage points below the national average in August 2000 (23.5 percent for black households and 23.6 percent for Hispanic households, compared with 41.5 percent for all households nationally). U.S. DOC (2000b) found that differences in income and education account for only about half the difference in Internet access among racial/ethnic groups.

Although Internet access is relatively low among black and Hispanic households, growth in access among these households is high. Access more than doubled for black households between December 1998 and August 2000 (from 11.2 percent to 23.5 percent) and also increased significantly for Hispanic households (from 12.6 percent to 23.6 percent). The growth rate in Internet access is higher in black and Hispanic households than in other groups.

- ♦ ***Sex.*** The disparity in Internet access between men and women has largely disappeared. In December 1998, 34.2 percent of men and 31.4 percent of women had home access to the Internet. By August 2000, 44.6 percent of men and 44.2 percent of women had home access.
- ♦ ***Age.*** There were great differences in Internet use among age groups in both December 1998 and August 2000, as shown in figure 8-18. In August 2000, more than 60 percent of teenagers and more than 50 percent of people ages 20–50 used the Internet. Individuals ages 50 and older were among the least likely to use the Internet; however, this age group had the greatest growth in use (compared with December 1998) of all age groups.
- ♦ ***Location.*** Internet access among households in rural areas was similar to access among households nationwide. In rural areas, 38.9 percent of households had Internet access in August 2000 compared with the nationwide rate of 41.5 percent.

Internet Access Among People With Disabilities. As shown in figure 8-19, people with disabilities are only half as likely to have access to the Internet as those without disabilities: 21.6 percent compared with 42.1 percent, respectively. Close to 60 percent of people with disabilities have never used a PC compared with less than 25 percent of people without disabilities. Among people with disabilities, those who have impaired vision and walking problems have lower rates of Internet access than people with other types of disabilities and are less likely to use a computer regularly than people

Figure 8-18
Internet use rates, by age: 1998 and 2000
(Internet use, any location)



SOURCE: U.S. Department of Commerce 2000. *Falling Through the Net: Toward Digital Inclusion, A Report on Americans' Access to Technology Tools*. Washington, DC.

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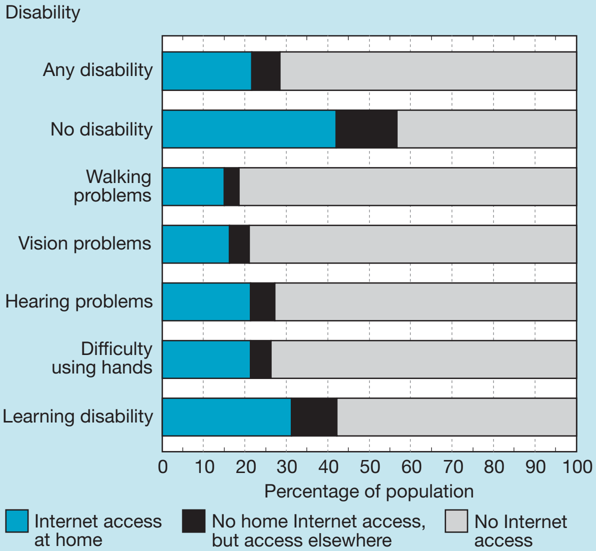
Figure 8-19.
Internet access, by disability: 1999



SOURCE: U.S. Department of Commerce. 2000. *Falling Through the Net: Toward Digital Inclusion, A Report on Americans' Access to Technology Tools*. Washington, DC: U.S. Department of Commerce.

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with hearing difficulties. This difference holds true for all age groups.

Lack of Internet access among people with disabilities is of special concern, because IT has the potential to improve the lives of these people. IT can make working from home more viable for people with limited mobility, turn written material into spoken language for visually impaired people, and turn speech into text for hearing-impaired people. IT does not automatically provide benefits to the disabled, however. Unless technologies are designed carefully, they can create new barriers. For example, websites frequently convey information in a visual form that is inaccessible to people who are visually impaired. Section 508 of the American with Disabilities Act requires that Federal agencies' electronic and information technology is accessible to people with disabilities, including employees and members of the public. This has made millions of Federal webpages more accessible.

The majority of individuals with disabilities are not employed (67.8 percent). Statistical analysis reveals a correlation between the employment status of people with disabilities and their home Internet access and regular use of PCs. The similarity in Internet access and computer use between people with and without disabilities is much greater among employed people than among nonemployed people. For example, among employed people, the rate of Internet access for people with disabilities is 78.3 percent of the rate for people without disabilities; among nonemployed people, that figure is only 46.6 percent.

Reasons for Not Going On-line. Why are some households and individuals not on-line? Lenhart (2001) found that half the adults in the United States do not have Internet access, and 57 percent of those who do not have access are not interested in getting access. This suggests that the booming growth of the U.S. Internet population in the past few years will slow down. Of those without Internet access now, 32 percent say they definitely will not get access, and another 25 percent say they probably will not get access. Among people without Internet access now, people over age 50 are the least likely to say they will go on-line eventually, and younger people are the most likely to say they will. The study also found that 54 percent of those who are not on-line believe the Internet is a dangerous thing, 51 percent say they do not think they are missing anything by staying away from the Internet, 39 percent say the Internet is too expensive, and 36 percent express concern that the on-line world is confusing and hard to negotiate.

DOC has found similar reasons that explain why some people do not have Internet access (U.S. DOC 2000b). Among surveyed households with annual incomes less than $15,000, one-third of respondents without Internet access (32.6 percent) cited cost as the reason and slightly more than one-quarter cited "don't want it" (26.6 percent) as the reason. In contrast, households with incomes greater than $75,000 reversed the order of importance: 30.8 percent cited "don't want it" as the reason for not having Internet access and only 9.4 percent cited cost as the reason.

Some households have discontinued their Internet access. In August 2000, 4.0 million households once had but did not currently have Internet access. That number was essentially unchanged from December 1998, when 4.1 million households reported discontinuing Internet access. In August 2000, the principal reasons cited by households for discontinuing Internet access were "no longer owns computers" (17.0 percent), followed by "can use anywhere" (12.8 percent) and "cost, too expensive" (12.3 percent). Other reasons were "don't want it" (10.3 percent), "not enough time" (10.0 percent), and "computer requires repair" (9.7 percent).

The data about people who have chosen not to have Internet access suggest that this population will remain substantial. However, as computer and telecommunication costs continued to decline and as more services become available over the Internet, some people who currently choose not to have Internet access may change their minds.

New Modes of Access. The digital divide in terms of Internet access among various demographic groups appears to be closing. However, as technology evolves, new concerns may arise about differences in access. About 10 percent of households with Internet access now have "broadband"[7] Internet access, primarily a cable modem (50.8 percent) or a digital subscriber line (DSL) (33.7 percent). Wireless and satellite technologies (4.6 percent) and other telephone-based technologies such as integrated services digital network (ISDN) (10.9 percent) account for much lower shares of broadband access. Rural areas lag be-

[7]The term "broadband" as used by U.S. DOC (2000b) includes the two most common technologies, DSL and cable modems, as well as other technologies such as ISDN. These technologies provide significantly faster data transmission, although some applications or connections may be slower than the 200 kilobits per second that the Federal Communications Commission defines as broadband.

hind central cities and urban areas in broadband penetration (7.3, 12.2, and 11.8 percent, respectively). Because broadband access is more expensive than dial-up access, its use probably will be less common in households with lower incomes.

IT Use at Home and in Communities

As the previous discussion illustrates, considerable information is now available about access to the Internet. However, information about the extent, nature, and impact of IT use in the home is more scarce. A review of the literature (National Science Foundation (NSF) 2001a) found that home computing in the 1980s has been analyzed extensively, but the more recent wave of computer adoption and Internet use by households has gone largely unexamined.

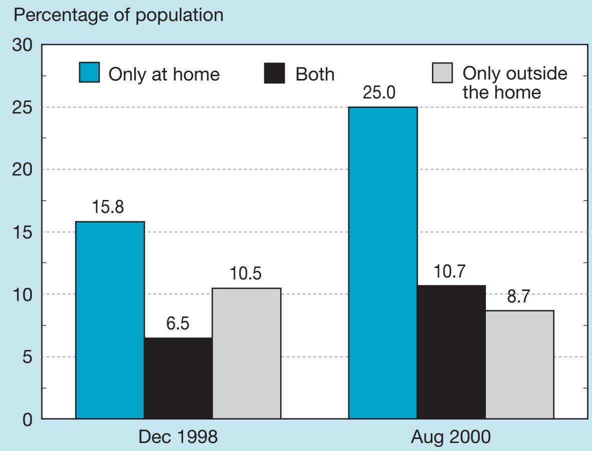
Indicators of How People Use Computers. Early research (NSF 2001a) found that home computing was used primarily for education, play, work, and basic word processing. Many early adopters used the computer less than they had initially expected. One long-term study found that nearly one-fifth of families quit using their home computer entirely within 2 years. It is unclear whether this underuse resulted from the inability of the technology to meet family needs, the lack of high-quality software for early computers, or other factors. Studies on early users of home computers found that children tended to use home computers more often and for longer periods than adults, and women and girls used home computers less often and less intensively than men and boys. Although playing games was the most common reason cited by children for using the computer, no one application actually dominated their use; they tended to use the computer about equally for playing games, learning, and writing.

More recent data provide a picture of trends in Internet access at home and outside the home (U.S. DOC 2000b). As shown in figure 8-20, 25.0 percent of the population had access to the Internet only at home as of August 2000, an increase from 15.8 percent in December 1998. The share of the population with access to the Internet both at home and outside the home also increased from December 1998 to August 2000, from 6.5 percent to 10.7 percent. In contrast, the percentage of the population with Internet access only outside the home declined from 10.5 percent to 8.7 percent.

Schools, libraries, and other public access points continue to serve people who do not have access to the Internet at home. For example, certain groups such as unemployed people, blacks, and Asians/Pacific Islanders are far more likely than others to use public libraries to access the Internet (U.S. DOC 2000b).

As shown in figure 8-21, e-mail is the Internet's most widely used application; 79.9 percent of the population used e-mail as of August 2000 and 70.0 percent of the population used e-mail as of December 1998 (U.S. DOC 2000b). Online shopping and bill paying saw the fastest growth in use. In August 2000, 16.1 percent of Internet users reported using the Internet to search for jobs; low-income users were more likely than others to use this application.

Figure 8-20.
Internet access at home and outside the home: 1998 and 2000



SOURCE: U.S. Department of Commerce. 2000. *Falling Through the Net: Toward Digital Inclusion, A Report on Americans' Access to Technology Tools*. Washington, DC: U.S. Department of Commerce.

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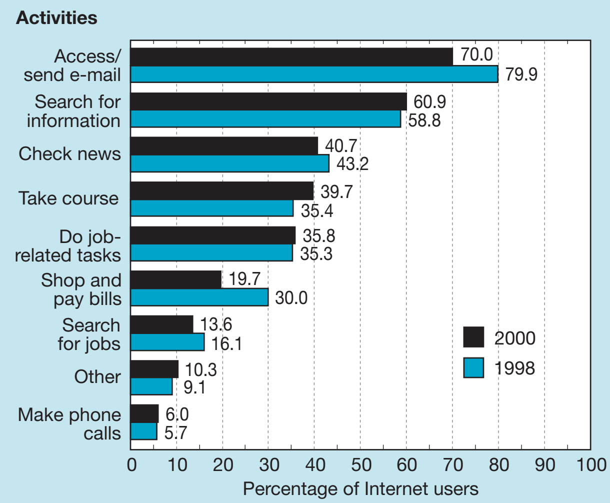
Figure 8-21.
Online activities: 1998 and 2000



SOURCE: U.S. Department of Commerce. 2000. *Falling Through the Net: Toward Digital Inclusion, A Report on Americans' Access to Technology Tools*. Washington, DC: U.S. Department of Commerce.

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Comparison Between Men and Women. The Pew Internet American Life Project (2000) noted that women have been more likely than men to use e-mail to enrich their important relationships and enlarge their networks. In the Pew study, more women than men said they were "attached" to e-mail and pleased with how it helped them. Among women who used the Internet, 60 percent said that e-mail exchanges have improved their connections to family members (compared with 51 percent of men), and 71 percent said that e-mail exchanges have improved their connections with significant friends (compared with 61 percent of men). Among women who said they e-mail friends, 63 percent said they communicated with significant friends more often than they had before they began using e-mail. Among both sexes, e-mail was found to increase communication in some relationships and to be a substitute for conversation in others.

The Pew study also found that women are more likely to go on-line to seek health and religious information, research new jobs, and play games. Men are more likely to go on-line to get news, shop, seek financial information, trade stocks, participate in on-line auctions, access government websites, and search for sports-related news.

On-line Medical Information. One of the top reasons Internet users access the Web is to obtain medical information. Fox and Rainie (2000) found that 52 million adults in the United States, or 55 percent of those with Internet access, have used the Web to get health or medical information. A majority of these users said they go on-line at least once a month for health information. Many said the resources they find on the Web have a direct effect on their decisions about health care and on their interactions with doctors. Among those who use the Internet to obtain health information, 48 percent said the advice they find on the Web has improved the way they take care of themselves, and 55 percent said Internet access has improved the way they get medical and health information. Among this same group, 92 percent said the information they found during their last on-line search was useful; 47 percent of those who sought health information for themselves during their last on-line search said the material affected their decisions about treatments and care.

IT Impact on Families and Individuals. Research into the actual impact of IT on families and individuals is extremely limited in scale and scope (NSF 2001a). However, some research has been conducted on time displacement, telework, psychological well-being, informatics and health care, and the effects of video games on children. The research indicates that use of IT in the home can be both beneficial and harmful. Some findings from this research are highlighted below.

Time Displacement. Home computing and Internet use apparently have not yet substantially displaced other forms of home media and entertainment, such as reading, watching television, or listening to the radio (NSF 2001a). Although some slight displacement of television viewing appears to have occurred, several analysts suggest that PCs and the Internet actually enhance media use because people begin to use other forms of media more often as they develop the habit of acquiring information.

Telework. The research on telework generally predates major changes in distributed work arrangements in large-scale organizations, so the findings from this research may have limited applicability to the contemporary workplace (NSF 2001b). The circumstances of telework have shifted over time. At first, employers allowed telework primarily to permit employees to work from home and more easily manage their family responsibilities. Now, many companies use telework as a strategy to satisfy and retain essential professional, technical, and managerial employees (NSF 2001b).

Studies indicate that telework can demonstrably enhance people's ability to balance work and family needs and reduce personal stress. On the other hand, telework can also disrupt important family dynamics and relationships and create psychological isolation. Most research on telework and distributed work has focused on efficiency and productivity, not on the impacts on individual workers or their families. The effects of telework clearly will differ from situation to situation, depending on whether an individual teleworks full time or only a few days a week, and whether an individual chooses to telework or is compelled to do so by an employer.

Psychological Well-Being. The evidence regarding the impact of computing on the psychological well-being of individuals is mixed. Some data suggest that increased Internet use is associated with social isolation, withdrawal, and stress, although actual Internet "addiction" may be limited to about 10 percent of Internet users and is not necessarily associated with how much time an individual spends on the Internet.

Kraut et al. (1998a) found evidence that increased use of the Internet was associated not only with increased social disconnectedness but also with loneliness and depression. The authors found an association between increased Internet use and "small but statistically significant declines" in social integration (as reflected by family communication and the size of an individual's social network), self-reported loneliness, and increased depression.

Conversely, Katz and Aspden (1997) found no statistically significant differences between Internet users' and nonusers' membership in religious, leisure, and community organizations (their analysis controlled for demographic differences such as age, sex, race, and education). They found that long-term Internet users actually belong to more community organizations than nonusers or former users. In addition, Katz and Aspden found that the vast majority of Internet users (whether recent or long term) reported no change in the amount of time they spent with family and friends on the telephone or in person.

Electronic Government

Like businesses, government agencies have long used IT in management information systems and research. With the advent of the Internet and especially the World Wide Web, however, IT has become a major means of government communication with citizens and other stakeholders. Governments at all levels are rapidly developing new ways of using IT to provide public services to businesses and individuals. Much government information is being made available on-line, and many government activities, from procurement to tax filings, are being conducted on-line.

The Federal Government On-line. The following are a few examples of on-line websites that provide information about the Federal Government (U.S. Working Group on Electronic Commerce 2000):

- FirstGov (<http://www.firstgov.gov>) is a single on-line portal that connects users to all government sites and has one of the largest collections of Web pages in the world. The site allows users to search all 27 million Federal agency Web pages at once.

- The Patent and Trademark Office's X-Search system (<http://www.uspto.gov>) enables anyone to use an Internet browser to search and retrieve, free of charge, more than 2.6 million pending, registered, abandoned, canceled, or expired trademark records. This is the same database and search system used by examining attorneys at the Patent and Trademark Office.
- The National Institutes of Health (NIH) maintains an on-line service (<http://www.ClinicalTrials.gov>) that provides users with information about the latest clinical research on cancer, heart disease, and other life-threatening illnesses.

Federal agencies also are making it possible for citizens to access forms and fill out applications on-line. The Social Security Administration has posted frequently used forms on its website, and individuals can apply for Social Security retirement benefits on-line. The U.S. Department of Agriculture's Forest Service has an on-line reservation system for government-administered campsites nationwide (<http://www.recreation.gov>). In addition, the U.S. Department of Education posts software and documentation for student aid on its website, and the Internal Revenue Service (IRS) posts tax forms and information on its websites and allows taxpayers to file electronically. These are but a few examples of Federal services available on-line.

The Federal Government also uses electronic procurement and payment. The General Services Administration is working toward using e-commerce to make procurement faster and cheaper. One element of this effort is the development of a U.S. Federal Public Key Infrastructure (PKI) to facilitate trusted communication among government agencies, between government agencies and their trading partners, and between the government and the public. PKI verifies the identity of the parties to an on-line transaction, ensures that data have not been altered in transit, prevents a party from falsely claiming that it did not send or receive a particular message, and makes certain that data remain confidential in transit. A number of agencies already have established operational PKIs that can authenticate and protect transactions.

The Federal Government now conducts the vast majority of its financial transactions—collections and expenditures—electronically. The U.S. Department of the Treasury collects electronically more than $1.3 trillion of Federal Government revenue—approximately two out of every three dollars collected (U.S. Working Group on Electronic Commerce 2000). In 1999, the Federal Government made 78 percent of its 959 million payments electronically, including 96 percent of salary payments, 81 percent of vendor payments, and 73 percent of benefit payments.

In addition to websites that offer agency-specific services and information, interagency websites target various segments of the population, such as small business owners, students, and senior citizens. These interagency websites are valuable to citizens because they integrate information across agencies (Fountain 2001a).

Cost Savings From Electronic Government. The cost savings from electronic government are potentially large (Fountain with Osorio-Urzua 2001). Movement from paper-based to Web-based processing of documents and payments typically generates administrative cost savings of roughly 50 percent and more for highly complex transactions (Fountain with Osorio-Urzua 2001).

State and Local Government On-line. State and local governments also are widely deploying electronic government concepts. Many significant reforms related to electronic government applications begin at the state level and then diffuse to Federal and local governments (Fountain 2001b).

Although electronic government services vary widely from state to state, several services are common to a number of states. The most common service, available in 32 states, allows users to find and apply for state government jobs on-line. The second most common service, available in 24 states, is electronic filing for personal income taxes.[8] Other common electronic government services give the public the ability to order vital records (birth, death, and marriage certificates), purchase fishing and hunting licenses and permits, search state government sex offender registries, and renew motor vehicle registrations—all on-line.

A few states offer less typical electronic government services that are both innovative and powerful. For example, North Carolina has three separate portals for citizens, businesses, and employees, with the categories and services offered in each portal oriented toward the type of visitor most likely to use it. Virginia allows users to create a personalized home page by customizing the interface and links to the services and features the user selects.

Local governments at the city, county, and town levels can vary dramatically in the socioeconomic characteristics of their citizenry and in the types of government services they offer. As a result, electronic government at the local level is applied in a variety of ways and with a variety of impacts.

The Indianapolis website (<http://www.IndyGov.org>) is a leading example of municipal government on the Web (Fountain 2001b). Innovative applications include geographical information systems (GIS) services that identify a user's local, state, and national representatives based on the user's address. A wealth of information is available on the Indianapolis website, including maps and descriptions of local recreational facilities. The website also integrates agency and departmental functions into a single, citywide portal.

Contra Costa County, in the San Francisco/San Jose region of California, also uses innovative Web services. The county's animal control department uses a digital camera to photograph stray and lost pets and then posts the photos on the Web, enabling pet owners to take a virtual visit to the pound to search for their lost pets. The county also is developing tools that allow citizens to use GIS data to design their own maps. For example, a resident could access the county Web portal, click on the GIS link, and enter a home address.

[8]The IRS's e-file program has helped State governments to implement or outsource electronic services easily. The e-file program allows commercial tax preparers to incorporate an Internet filing capability into their tax software and makes it easy for states to adopt systems compatible with e-file and the commercial software.

The individual then could query a number of GIS data sets, including property parcels and values, school locations, police and fire station locations, risk of natural disaster (flood, earthquake, etc.), political districts, and environmental hazards, and quickly produce a customized map that shows all the data requested for the area surrounding the address given.

The Internet also is affecting political processes in the United States and around the world. Political candidates are establishing websites to communicate with voters, solicit funds, and organize volunteers. Interest groups are using e-mail and websites to organize and express their views. In some cases, groups that would be very difficult to organize through traditional means, such as scientists or engineers in different parts of the country, can be mobilized through e-mail to express their views to Congress on a timely issue. Some groups are experimenting with voting via the Internet. See sidebar, "Internet Voting."

IT and S&E

The S&E community developed IT, in many cases for S&E applications. Scientists and engineers have been among the earliest and most intensive users of many IT applications. It is not surprising that IT has played a major role in the practice of S&E and in the evolution of S&E institutions.

Advances in computing, information storage, software, and networking are all leading to new tools for S&E, ranging from automated scientific instruments to supercomputers for modeling and simulation. IT has made possible new collections of data and new ways to access scientific information. As IT has advanced, applications for S&E have become more powerful and less expensive, and many applications, such as modeling and databases, have migrated from large mainframe computers and supercomputers to desktop computers. IT also has made possible new modes of communication among scientists, allowing them to collaborate more easily. IT affects how research

Internet Voting

Many people have expressed a strong interest in using the Internet to make voting more convenient. It is hoped that such a practice would increase participation in elections. Internet voting is seen as a logical extension of Internet applications in commerce and government. Election systems, however, must meet high standards of security, secrecy, equity, and many other criteria. These requirements make the development of Internet voting much more challenging than most commerce or government applications of the Internet.

The National Science Foundation supported a study and workshop to analyze the issues associated with Internet voting (Internet Policy Institute 2001). The study concluded that remote Internet voting (e.g., voting from the home or office) poses significant risks to the integrity of the voting process and should not be widely used in public elections until substantial technical and social science issues are addressed. On the other hand, it would be possible to use Internet voting systems at polling places, and such systems could offer greater convenience and efficiency than traditional voting systems. Voters could eventually choose to cast their ballots from any one of many polling places, and the tallying process would be both fast and certain. Because election officials would control both the voting platform and the physical environment, managing the security risks of such systems is feasible. Over time, it would also be possible to have Internet voting in kiosks—voting machines located away from traditional polling places—at convenient locations such as malls, libraries, or schools. Kiosk voting terminals pose more challenges than poll-site systems, but most of the challenges could, at least in principle, be resolved through extensions of current technology.

A broad range of research is needed on Internet voting systems. Research topics include the following:

- Approaches to meeting the security, secrecy, scalability, and convenience requirements of elections.
- Development of reliable poll-site and kiosk Internet voting systems that are not vulnerable to any single point of failure and cannot lose votes.
- Development of new procedures for continuous testing and certification of election systems, as well as test methods for election systems.
- Incorporation of human factors into design for electronic voting, including development of appropriate guidelines for designing human interfaces and electronic ballots and development of approaches for addressing the needs of the disabled.
- The economics of voting systems, including comparative analyses of alternative voting systems.
- The effects of Internet voting on participation in elections, both in general and with regard to various demographic groups, especially those with less access to or facility with computers.
- The effects of Internet voting on public confidence in the electoral process and on deliberative and representative democracy.
- The implications of Internet voting for political campaigns.
- Legal issues associated with and the applicability of existing statutes to Internet voting, including jurisdiction, vote fraud, liability for system failures, international law enforcement, and electioneering.

is conducted, how new products and processes are developed, and how technical information is communicated.

IT also is influencing technological innovation in society. These influences reflect not only changes in R&D processes but also changes in the market environment for innovation and the organization of innovative activities. Although some of these effects are most visible in the IT industry itself, IT also affects other industries, higher education, and the job market for scientists and engineers.

In general, relatively little scholarly research has been conducted on how IT affects S&E, and even less research has been performed on how IT affects innovation. This section highlights some of the limited work that has been done.

IT and R&D

IT has provided new tools for the simulation and modeling of complex natural, social, and engineering systems. It has enabled new methods of data collection and has made possible the creation of massive, complex, and shared data sets. It has changed the way scientific knowledge is stored and communicated. IT has facilitated the sharing of computational resources and scientific instruments among scientists and engineers in different locations and has aided communication and collaboration among large groups of researchers.

Advances in both hardware and software have supported new IT tools for R&D. Advances in software have been critical to the success of supercomputers that use thousands of microprocessors and have also enabled the analysis and visualization of complex problems. Software engineering also is enabling security technologies, distributed information management, high-confidence software systems, and numerous other areas of research that are needed in today's most advanced IT applications

The role of IT is not uniform across all areas of S&E. Some areas of research, such as high-energy physics, fluid dynamics, aeronautical engineering, and atmospheric sciences, have long relied on high-end computing. The ability to collect, manipulate, and share massive amounts of data has long been essential in areas such as astronomy and geosphere and biosphere studies (Committee on Issues in the Transborder Flow of Scientific Data 1997). More recently, IT has spread from its historical stronghold in the physical sciences to other natural sciences, engineering, social sciences, and the humanities and has become increasingly vital to sciences such as biology that historically had used IT less extensively.

Modeling and Simulation

Modeling and simulation have become powerful complements to theory and experimentation in advancing knowledge in many areas of S&E. Simulations allow researchers to run virtual experiments when actual experiments would be impractical or impossible. As computer power grows, simulations can be made more complex, and new classes of problems can be realistically simulated. Simulation is contributing to major advances in weather and climate prediction, computational biology, plasma science, high-energy physics, cosmology, materials research, and combustion, among other areas. New visualization techniques for displaying simulation data in comprehensible formats have played an important role.

Simulation also is used extensively in industry to test the crashworthiness of cars and the flight performance of aircraft (U.S. Department of Energy (DOE)/NSF 1998) and to facilitate engineering design. Computer-aided design (CAD) programs can use CAD data to visualize, animate, simulate, validate, and assemble parts digitally. In some cases, CAD programs can allow a designer to insert digital representations of humans into virtual worlds to test for ergonomics, manufacturability, maintainability, safety, and style (Brown 1999). The goal of such an approach is to address these issues early in the design stage and reduce the need for physical mock-ups and rework. Both aircraft and automobile manufacturers use CAD approaches extensively.

Modeling and simulation capabilities continue to improve at a rapid rate. DOE's Accelerated Strategic Computing Initiative program, which uses simulation to replace nuclear tests, deployed the first trillion-operations-per-second (teraops) computer in December 1996. The program deployed a 12.3-teraops computer in June 2000 and plans to operate a 100-teraops computer (with 50 terabytes of memory and 130 petabytes of archival storage) by 2005 (National Science and Technology Council 1999; U.S. DOE 2001). Research funded by the Defense Advanced Research Projects Agency, the National Aeronautics and Space Administration (NASA), and the National Security Agency is evaluating the feasibility of constructing a computing system capable of a sustained rate of 1,015 teraops (1 petaflop).

Terascale computing is expected to have applications in genetic computing, global climate modeling, aerospace and automotive design, financial modeling, and other areas. To use data from human genome research, for example, new computational tools are needed to determine the three-dimensional atomic structure and dynamic behavior of gene products, as well as to dissect the roles of individual genes and the integrated function of thousands of genes. Modeling the folding of a protein to aid in the design of new drug therapies also takes extensive computing power (U.S. DOE/NSF 1998). Celera Geonomics Corporation (a genomics and bioinformatics company), Sandia National Laboratories, and Compaq entered into a partnership in January 2001 to develop algorithms and software for genomic and proteomic applications of supercomputers in the 100-teraops to 1-petaflop range, with the petaflop computer expected by 2010. Pattern recognition and data-mining software also are critical for deciphering genetic information (Regalado 1999).

Many scientists expect IT to revolutionize biology in the coming decades, as scientists decode genetic information and explore how it relates to the function of organisms (Varmus 1999). New areas of biology such as molecular epidemiology, functional genomics, and pharmacogenetics rely on DNA data and benefit from new, information-intensive approaches to research.

IT and Data

IT has long been important in collecting, storing, and sharing scientific information. More recently, IT has enabled automated collection of data. For example, automated gene sequencers, which use robotics to process samples and computers to manage, store, and retrieve data, have made possible the rapid sequencing of the human genome, which in turn has resulted in unprecedented expansion of genomic databases (Sinclair 1999). In many scientific fields, data increasingly are collected in digital form, which facilitates analysis, storage, and dissemination. For example, seismic data used to measure earthquakes were once recorded on paper or film but now are usually recorded digitally, making it possible for scientists around the world to analyze the data quickly.

By 1985, 2,800 scientific and technical electronic databases (both bibliographic and numerical) already existed (Williams 1985). At that time, primarily information specialists accessed electronic databases, and many of the databases were available only for a fee. Over time, databases have expanded in number and size, and many are now widely accessible on the World Wide Web. See sidebar, “Examples of Shared Databases.”

Electronic Scholarly Communication

Originally developed primarily as tools for scientific communication, the Internet and the World Wide Web continue to have a significant impact on scholarly communication in scientific and technical fields. An increasing amount of scholarly information is stored in electronic forms and is available through digital media.

Electronic Scholarly Communication Forms. Scholarly information can be placed on-line in several different forms, most of which are expanding rapidly. These forms may be classified as follows (drawing on Kling and McKim 1999 and 2000):

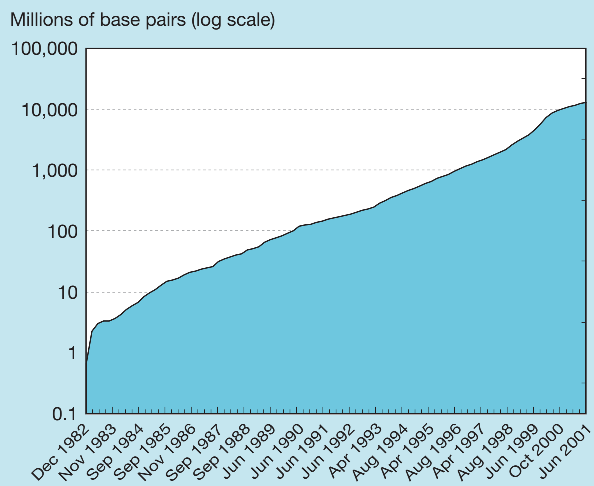
- **Pure electronic journals**—an edited package of articles that is distributed to most of its readers in electronic form. Examples include the *World Wide Web Journal of Biology* and the *Journal of the Association for Information Systems.*
- **Hybrid paper-electronic (p-e) journals—**a package of peer-reviewed articles that is distributed primarily in pa-

Examples of Shared Databases

Large shared databases have become important resources in many fields of science and social science. These databases allow researchers working on different pieces of large problems to contribute to and benefit from the work of other researchers and shared resources. Examples of such databases include the following:

- GenBank (<http://www.ncbi.nlm.nih.gov/Genbank/>) is the National Institute of Health’s annotated collection of publicly available DNA sequences. As of June 2001, GenBank contained approximately 12.9 billion base pairs from 12.2 million sequence records. (See figure 8-22.) The number of nucleotide base pairs in its database has doubled approximately every 14 months. As part of a global collaboration, GenBank exchanges data daily with European and Japanese gene banks.
- The Protein Data Bank (<http://www.rcsb.org/pdb/>) is the worldwide repository for the processing and distribution of three-dimensional biological macromolecular structure data (Berman et al. 2000).
- The European Space Agency (ESA) Microgravity Database (<http://www.esa.int/cgi-bin/mgdb>) gives scientists access to information regarding all microgravity experiments carried out on ESA and National Aeronautics and Space Administration missions by European scientists since the 1960s.
- The Tsunami Database (<http://www.ngdc.noaa.gov/ seg/hazard/tsu.html>) provides information on tsunami events from 49 B.C. to the present in the Mediterranean and Caribbean Seas and the Atlantic, Indian, and Pacific Oceans. It contains information on the source and effects of each tsunami.
- The Earth Resources Observation Systems Data Center (<http://edcwww.cr.usgs.gov/>) houses the National Satellite Land Remote Sensing Data Archive, a comprehensive, permanent record of the planet’s land surface derived from almost 40 years of satellite remote sensing. By 2005, the total holdings will come to some 2.4 million gigabytes of data.

Figure 8-22.
Growth of GenBank



SOURCE: Genetic Sequence Data Bank, NCBI-GenBank Flat File. Available at <ftp://ncbi.nlm.nih.gov/genbank/gbrel.txt>.

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per form but is also available electronically. Examples include *Science On-line, Cell, Nature,* and many others.

- **Electronic print (e-print) servers—**preprint or reprint servers on which authors in specific fields post their articles. The original and most widely copied preprint server is the Los Alamos physics preprint server (<http://arxiv.org/>). Started in 1991 by Los Alamos physicist Paul Ginsparg as a service to physicists in a small subfield of physics, this server has grown to cover many fields of physics, astronomy, mathematics, and computation. Other preprint servers have been developed to serve other fields, but most fields do not use preprint servers as extensively as physics.
- **Non-peer-reviewed publications on-line—**includes electronic newsletters, magazines, and working papers.
- **Personal Web pages—**maintained by individuals or research groups. Many scholars post their own work on these sites, which may include "reprints" of published material, preprints, working papers, talks and other unpublished material, bibliographies, data sets, course material, and other information of use to other scholars.

In addition, a number of services facilitate searching and provide abstracts and (in some cases) full text of articles in paper or p-e journals. These services include LexisNexis™, databases of journals sold to academic libraries, and public sources such as PubMed Central (<http://www.pubmedcentral.nih.gov/>) and PubSCIENCE (<http://www.osti.gov/pubsci>).[9] These can be considered elements of digital libraries. See sidebar, "Digital Libraries."

An example of rapid expansion in electronic scholarly communication is the Los Alamos preprint server (<http://arxiv.org/>), which continues to grow in terms of both submissions and connections. As of April 2001, it was receiving more than 2,500 new submissions each month and averaging more than 100,000 connections (for searching, reading, or downloading papers) each day. It has become the main mode of communication in some fields of physics, and 17 mirror sites have been established around the world to provide alternative access to the information in it.

Kling and McKim (2000) note that one should not expect the preprint server mode of electronic communication to expand to all fields, however. High-energy physics had a culture of wide sharing of preprints before the advent of the World Wide Web, and researchers in this field now use electronic communication extensively. Molecular biologists, by contrast, traditionally shared preprints only among smaller groups and continue to rely more on paper journals. Different fields have different attitudes about posting material on the Web prior to publication in a peer-reviewed journal. In physics, such posting is standard practice; in medicine, it is viewed as dangerous because the public may make medical decisions based on non-peer-reviewed science. The absence of e-print servers in fields such as atmospheric research, oceanography, and climate science is evidence of substantial differences in scholarly communication across fields of science.

Electronic journals also have been expanding rapidly. The Association of Research Libraries 2000 directory of scholarly electronic journals and academic discussion lists (Mogge and Budka 2000) identifies 3,915 peer-reviewed electronic journals, up from 1,049 in 1997. Friedlander and Bessette (2001) cite estimates ranging from 3,200 to 4,000 e-journals in science, technology, and medicine. Most of these are not electronic-only journals but rather are electronic versions of, or supplements to, print journals.

Electronic Scholarly Communication Benefits. Electronic scholarly communication has many potential benefits. Electronic search tools make it possible for scholars to find information more easily and quickly, and scholars do not have to worry about whether journals are missing from the library. Electronic documents potentially offer richer information than print documents. They are not constrained by page limits and can contain multimedia presentations or computer programs and data as well as text, thus enriching the information and facilitating further work with it. Additional references, com-

Digital Libraries

The digital library is a concept related to both scholarly communication and scientific databases. The concept encompasses a variety of digital collections of information, including digital versions of traditional library, museum, and archive holdings. The World Wide Web is considered an extensive but rudimentary digital library because search methods typically cover only a small part of the collections (President's Information Technology Advisory Committee 2001). Newspaper archives and genomic databases also are considered digital libraries.

A vision set forth for digital libraries is that they will let all citizens, anywhere and anytime, use any Internet-connected digital devices to search and access all of human knowledge (President's Information Technology Advisory Committee 2001). Key issues in achieving this vision include:

- improving the ability to search for information, in part by improving the "metadata" systems for describing and organizing collections;
- improving the human interfaces with the libraries;
- improving the ability to store and retrieve materials across diverse independent collections;
- developing long-term storage technologies and efficient procedures for transferring ephemeral content into long-term storage; and
- determining how to manage intellectual property rights for digital collections.

[9]PubSCIENCE is a World Wide Web service developed by DOE to facilitate searching and accessing of peer-reviewed journal literature in the physical sciences and other energy-related disciplines.

ments from other readers, or communication with the author can be linked to the document.

Electronic communication is generally thought to speed the dissemination of scientific information, and this is generally thought to increase scientific productivity. However, some scientists suggest that the Web, by speeding electronic communication, can encourage scientists to rush to become part of the latest trend, leading them to abandon other paths of research too quickly (Glanz 2001b).

There are also potential advantages for libraries. Many patrons can access the same electronic information at the same time without needing to visit the library, electronic archives eliminate the space requirements of old journal collections, and electronic media help libraries stretch limited financial resources, especially for accessions.

Electronic documents also have potential economic benefits. Once a document is prepared in electronic form, the marginal cost of providing it to additional readers is very low. Electronic documents also offer the benefit of accessibility. Electronic documents can be made available over the Internet to scholars around the world who do not have access to major research libraries. For example, the Los Alamos archive is allowing scientists in geographically isolated and small institutions to participate in leading-edge research discussions (Glanz 2001a). Several publishers have announced that they will provide free electronic medical journal access to medical schools, research laboratories, and government health departments in poor countries (Brown 2001).

Electronic Scholarly Communication Issues. All of the factors mentioned above combine to exert strong pressures for making scholarly information available electronically. Although these potential benefits support the rapid expansion of electronic communication, several issues remain to be resolved, including issues related to function, economics, and archiving.

Function. Although nonrefereed electronic publications (such as preprint servers) can be much less expensive than print journals (Odlyzko 1997), such publications do not perform all of the functions of the traditional system of printed academic journals. For example, journals organize articles by field and manage peer-review processes that help to screen out bad data and research, scholars achieve recognition through publication in prestigious journals, and universities base hiring and promotion decisions on publication records. For this reason, preprint servers are not likely to replace peer-reviewed journals.

Economics. For peer-reviewed journals (in either paper or electronic form), editing and refereeing of manuscripts and general administration account for a large share of costs (Getz 1997). At least initially, these costs remain about the same for electronic journals. In addition, electronic journals have costs associated with acquiring and implementing new technology and formatting manuscripts for electronic publication.

Electronic publication also can affect the revenue stream of print publishers. If a publisher provides a site license for a university library that enables anyone on campus to read the journal, individual subscriptions from that campus may decline. Moreover, advertisers may find electronic journals less attractive than print versions.

Publishers are currently experimenting with different ways of pricing electronic journals. Some publishers provide separate subscriptions for electronic and print versions, and the price of the electronic subscription may be higher or lower than the price of the print subscription. Others provide the electronic version at no charge with a subscription to the print version. Some publishers offer free on-line access to selected articles from the print version and regard the on-line version as advertising for the print version (Machovec 1997). Publishers of fee-based electronic journals generally protect their information from unauthorized access by making the journals accessible only to certain Internet domains (such as those of universities that have acquired a site license) or by using passwords.

Electronic resources represent an increasing share of library costs. The Association of Research Libraries (Kyrillidou 2000) reported that electronic resources (e.g., indexes and subscriptions to on-line journals) increased from 3.6 percent of library material expenses in 1992–93 to 10.5 percent in 1998–99. Overall, serial costs (including both paper and electronic serials) increased over this same period, from a median of $161 per serial in 1992 to $284 in 2000. Library budgets are under increasing pressures as they seek to satisfy demands for both paper and electronic journals.

Archiving. Another key issue is the archiving of electronic publications (Friedlander and Bessette 2001). One fundamental issue is the technical question of how to maintain records over the long term, because the electronic medium degrades and electronic formats change. Another fundamental issue is the underlying tension in electronic media between the opportunity to revise and update papers to maintain currency and the need to maintain the record. Another question to be addressed is whether an entire issue of an on-line magazine or newspaper should be preserved or whether it suffices to create a database of individual stories that can be individually retrieved but can never be reconstituted into the actual issue as it existed on the day readers first read the news. Other questions relate to responsibility for long-term preservation (whether publishers or libraries should be primarily responsible), copyright (how to issue and enforce copyrights), and maintenance (as technologies evolve, the particular technology required to view a given file may become obsolete, effectively eliminating the record).

Collaboration

Computer networking was developed as a tool for scientists and engineers, and e-mail and file transfers have long supported collaboration among scientists and engineers. Shared databases, intranets, and extranets have helped geographically separated scientists and engineers work together.

Scientific collaboration, as measured by the increase in the percentage of papers with multiple authors, has been increasing steadily for decades. (See chapter 6, “Industry, Technology, and the Global Marketplace.”) Walsh and Maloney (2001) have found that computer network use is associated with more geographically dispersed collaborations as well as more productive collaborations.

Collaborations have been growing larger in a number of fields, often because scientists are pursuing increasingly complex problems and, in some cases, also because agency funding programs encourage multi-investigator and multidisciplinary research teams. These collaborations are facilitated by IT, especially e-mail and the World Wide Web. Large-scale scientific collaborations may especially benefit from new IT. The number of research papers with authors from multiple countries or institutions has increased rapidly, a trend that has coincided with the rapid expansion of the Internet. (See figure 8-23.)

Over the past decade, advanced tools have emerged to support “collaboratories”—geographically separate research units functioning as a single laboratory (CSTB 1993). These technologies allow:

- remote access to scientific instruments over the Internet, making it possible for researchers from different sites to use a single major scientific instrument (such as a synchrotron at a national laboratory) as a network of instruments operating at different places:
- Internet-based desktop videoconferencing;
- shared access to databases and computer simulation;
- shared virtual workspaces, such as “white boards” on which researchers can sketch ideas; and
- shared electronic laboratory notebooks to capture the details of experiments.

These tools were originally developed and demonstrated through several collaboratory pilot projects, including the NSF-sponsored Space Physics and Aeronomy Research Collaboratory (<http://intel.si.umich.edu/sparc/>) and the DOE-sponsored Materials MicroCharacterization Collaboratory (<http://tpm.amc.anl.gov/MMC>) and Diesel Combustion Collaboratory (<http://www-collab.ca.sandia.gov/snl-dcc.html>).

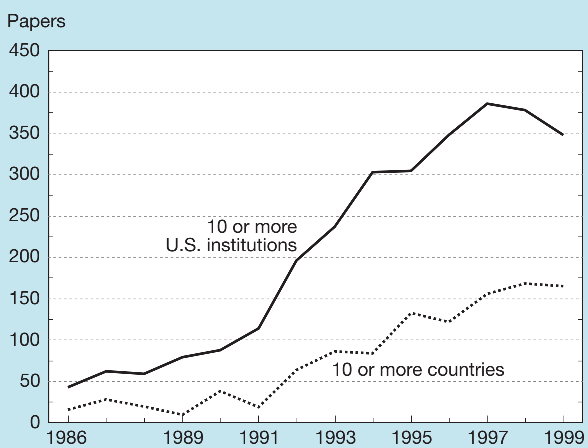
The collaboratory concept has moved beyond pilot projects to the point where many new large-scale projects have collaboratory components. Many of the tools used in the early pilot projects, such as Internet-based videoconferencing, are now available in inexpensive commercial software. Examples of new major research projects that have a collaboratory component include the following:

- The NIH-funded Great Lakes Regional Center for AIDS Research, a collaboratory of Northwestern University, University of Wisconsin-Madison, University of Michigan-Ann Arbor, and University of Minnesota-Minneapolis investigators (<http://www.greatlakescfar.org/cfar/>).
- NIH’s Human Brain Project, a cooperative effort among neuroscientists and information scientists to develop tools for brain research (<http://www.nimh.nih.gov/neuroinformatics/index.cfm>). This project emphasizes tools to aid collaboration between geographically distinct sites.
- The NSF-funded George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES), a national networked collaboratory of geographically distributed, shared-use experimental research equipment sites (with teleobservation and teleoperation capabilities) for earthquake engineering research and education. When operational in 2004, NEES will provide a network of approximately 20 equipment sites (shake tables, centrifuges, tsunami wave basins, large-scale laboratory experimentation systems, and field experimentation and monitoring installations) (NSF 2001b).
- The NSF-funded Distributed Terascale Facility (DTF) will be a multi-site supercomputing system. It will perform 11.6-trillion calculations per second and store more than 450-trillion bytes of data, and will to link computers, visualization systems and data at the National Center for Supercomputing Applications in Illinois, the San Diego Supercomputer Center (SDSC) in California, Argonne National Laboratory in suburban Chicago and the California Institute of Technology in Pasadena (NSF 2001c).

Although collaborative research projects are being designed around IT, it is unclear whether virtual collaborations will be as successful as colocated collaborations. Teasley and Wolinsky (2001) note that collaboratories have limits. Social and practical acceptability are the primary challenges. Collaboratories do not replace the richness of face-to-face interaction, and concerns about trust, motivation, data access, ownership, and attribution can affect collaboratory performance.

Finholt (2001) notes that, although studies of early collaboratories suggest that e-mail and computer-mediated communication enhance scientific productivity and support

Figure 8-23.
Papers with authors from 10 or more countries or 10 or more U.S. institutions: 1986–1999



SOURCE: CHI Research, Inc.

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larger and more dispersed collaborations, electronic communication alone is not enough to enable broader collaborations. Collaboratory technologies have not dispersed to scientific users as fast as other Internet technologies (such as e-mail or the World Wide Web), which suggests that major challenges may be involved in supporting complex group work in virtual settings. Most practices and routines of research groups assume a shared space, and transferring these practices to virtual spaces can be difficult. Collaboratories may benefit graduate students and "nonelite" scientists the most, because they are the members of the scientific community least able to afford the costs of travel. Also, the increase in outside participation that results from virtual collaboration may create distractions for top researchers.

Olson and Olson (2001) note that distance collaborations work best when the work groups have much in common, the work is loosely coupled, and the groups have laid both the social and technical groundwork for the collaboration. Lacking these elements, distance collaborations are much less likely to succeed.

Collaboratory technologies raise interesting questions about the effects of IT on the organization of science and technology (S&T). Will multi-institution, electronically enabled collaborations become the norm for large-scale science projects? Will collaboratories make science more open to nonelite scientists? How do collaboratory technologies affect the productivity of S&T?

IT and Innovation

In addition to its interactions with R&D, IT influences several other elements of the innovation process, including the market environment for and the organization of innovation. The Council of Economic Advisers (2001) notes that the U.S. economy in the late 1990s was characterized by the high rate of technological innovation and by the central role of IT. The council observes that innovation in the "new" economy appears to have changed in several ways, including the intense competition and positive feedback that drive innovation, the mechanisms for financing innovation, the sources of R&D, and the innovation process itself. IT is involved in each of these changes, and many of the changes are most visible in the IT sector.

Market Environment for Innovation

The rapid pace of technological advances, together with the expectation that this pace will continue (see sidebar, "Moore's Law"), has led to an environment in which companies in most industries know they must continually innovate. As noted above, intense competition and feedback drive the development and adoption of new technologies. The availability of one technology stimulates demand for complementary technologies, which in turn lowers production costs and encourages further demand for the initial technology.

The Internet may be stimulating innovation by forcing many industries to innovate. For example, in the food industry, the fact that some companies are using electronic procurement is forcing others to do the same (Hollingsworth 1999). In some cases, IT may increase competition simply by making markets more global and bringing firms in contact with more competitors.

Lewis (2000) notes that telecommunications and IT have accelerated business processes. Technology adoption and diffusion rates are faster than they were in previous decades. In addition, the information economy has led to network effects (see sidebar, "Metcalfe's Law") in many areas, giving a major advantage to the company that is the first to bring a new product to market. If a company is not the first to market, then it needs to match and improve on the new product very quickly. The consequence of this environment is that technology transfer must occur faster and faster. Lewis argues that corporate R&D must change its traditional way of doing business, which is too slow.

The rapid improvement in IT has created opportunities in new applications such as secure Web servers or e-commerce software, which in turn create opportunities for new businesses. New forms of business activity (such as electronic marketplaces) and new IT-enabled business processes present many opportunities for innovation.

Organization of Innovation

Dewett and Jones (2001) review the literature on how IT affects organizational characteristics and outcomes. They note that although the literature contains very little information on the specific role of IT in promoting innovation, it is possible to identify many innovation-related effects of IT on organizations, including the following:

- IT can enhance the knowledge base available to each employee, enable faster scanning and monitoring of the external environment, and improve both the employees' and the organization's knowledge of best practices and relevant leading-edge technologies.
- IT can mitigate the tendency toward specialization (which can reduce people's ability to understand the context of the organization) and also can help promote innovation by better connecting specialists to the market.
- IT may increase absorptive capacity, which is the ability of an organization to recognize the value of external information, assimilate it, and apply it commercially.
- By helping organizations codify their knowledge bases, IT can promote the diffusion of knowledge.
- IT has helped organizations streamline product design by replacing traditional sequential processes with parallel processes in which employees in different functions work simultaneously, with continual interaction through electronic communication.
- IT is changing organizational forms and allowing virtual organizations. New IT-enabled organizational forms can be more responsive to pressures such as heightened market volatility, the globalization of business, increased un-

certainty in the economy, and demographic changes in labor and consumer sectors.

In contrast, electronic communication may hinder innovation by decreasing informal communication and may also lead to information overload.

Thus, IT has many possible effects on organizations, and these effects suggest a considerable positive influence on innovation. It is important to keep in mind, however, that scholarly literature on this subject is sparse.

Johannessen, Olaisen, and Olsen (2001) suggest that because IT more effectively transfers explicit knowledge than tacit knowledge, it may lead to the mismanagement of innovation. Explicit knowledge is relatively easy to express in symbols, digitize, and transfer. Tacit knowledge is rooted in practice and experience and typically is transmitted through training and doing. Companies typically focus IT investment on the explicit portion of their knowledge base and deemphasize the tacit portion. Yet much of the research literature argues that tacit knowledge is critical in determining how well a company can innovate and compete.

IT also has led to changes in the organization of innovation beyond the boundaries of individual organizations. The Council of Economic Advisers (2001) notes that innovation traditionally has been isolated within large companies. Today, innovation increasingly is performed by both large and small companies that collaborate with each other and with academic institutions and government agencies.

With the expansion of the world's supply of scientists, technologists, and knowledge workers and of the knowledge bases available to them, access to external knowledge sources is becoming an increasingly important factor in the ability of organizations to participate in innovation. IT has helped organizations coordinate highly dispersed innovation activities by providing them with new management techniques, software, and communication systems. One aspect of the trend toward dispersion of innovation activities is the outsourcing of innovation. Pharmaceutical companies have long outsourced basic research to universities, institutes, and government laboratories. Many large pharmaceutical companies rely on small technology companies for innovation and then acquire these companies. In the computer and automotive industries, manufacturers have long relied on component makers for design and engineering work. Much of the innovation in these industries takes place at the interface between manufacturers and their innovative suppliers. IT has made outsourcing more attractive for companies (Quinn 2000) by facilitating the process with advances in modeling and simulation, collaborative tools, and management software.

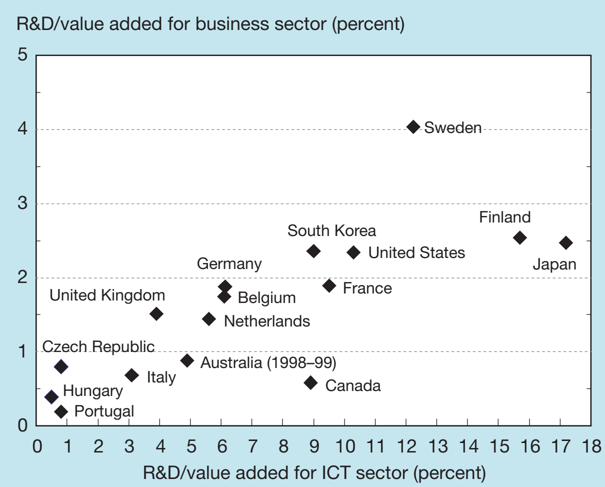
One example of new organization in innovation is open source software development (Lerner and Tirole 2001). In open source software development, the source code is made broadly available. Users can modify the software, but their modifications are also returned to the community or organization that oversees the development of the software. A number of open source software programs are widely used, including Linux (a PC operating system), Apache (Web server software), and Sendmail (which underlies e-mail routing on the Internet). Participation in open source projects is voluntary. Although participants appear to be motivated by altruism, they do benefit from their efforts. Programmers who donate their time benefit from recognition, and companies that support the programmers benefit from improved programs and better monitoring and absorption of external technology (Lerner and Tirole 2001). A number of companies make money not by selling the software, which is freely available, but by selling complementary services (e.g., documentation, installation software, and utilities). The President's Information Technology Advisory Committee recommended that the Federal Government support open source software development for high-end computing.

Innovation in IT

The IT sector accounts for a large and growing part of R&D and innovation in the United States and other countries. The information and communication technology (ICT) sector is more R&D intensive than industry as a whole. Figure 8-24 compares the ratio of R&D to the value added for the ICT sector with the same ratio for the overall business sector in OECD countries. For most countries, the ICT sector is about five times more R&D intensive than the business sector as a whole; however, countries vary widely in the R&D intensity of their IT industries. Some of the countries that are the most innovative in IT, including Sweden, Finland, Japan, and the United States, have the most R&D-intensive ICT industries.

Analyses of patent data suggest that innovation in IT is somewhat different from innovation in other areas of S&T. Hicks et al. (2001) found that compared with other areas of technology, IT patents cite scientific literature less exten-

Figure 8-24.
Ratio of R&D to value added in the ICT and total business sectors: 1997



ICT = Information and communications technologies

SOURCE: Organisation for Economic Co-operation and Development. 2001. *Measuring the ICT Sector*. Paris. Tables 2 and 3. Available at <http://www.oecd.org/dsti/sti/it/prod/measuring_ict.htm>.

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sively.[10] In addition, the median age of patents cited by IT patents (termed the technology cycle time) is less than the median age of scientific papers cited (termed the science cycle time). Technology cycle times are faster in IT (6–6.5 years) than in other areas of technology. The analysts concluded that IT patents cite other technology patents more extensively than scientific papers because IT is moving too fast for scientific research to keep up.

Growth in IT patenting activity does not seem to be accompanied by growth in research publishing activity (Hicks et al. 2001). Based on documents referenced in patents, IT patents seem to draw on a particularly diverse set of nonpatent, nonresearch technical documentation that includes nonpatented software. It appears that nonresearch technical work may underlie innovation in IT more extensively than is the case in other technologies and that IT innovation is less directly dependent on scientific research than are many other technologies. Hicks et al. (2001) also note that patenting (one measure of innovative activity) is accelerating in IT. The IT patents share of all U.S. patents increased from 9 percent in 1980 to 25 percent in 1999. IT patents per $1 million of company R&D expenditures nearly doubled between 1990 and 2000. Similar increases were not observed in other areas. Although such statistics might simply indicate an increased propensity to patent in the IT sector, the extent to which IT patents are cited by other patents has increased, which suggests that the quality of IT patents has not deteriorated.

IT and Higher Education

IT pervades higher education. As the demand for IT workers has grown, university priorities have shifted accordingly, and a separate certification and training system for IT workers also has emerged. IT is increasingly used in instruction, and distance education continues to expand. IT may lead to further restructuring of colleges and universities. This section highlights some of the ways in which IT is affecting higher education.

IT Credentialing

Adelman (2000) analyzes the new system of credentialing that has arisen in ICT industries during the past decade. Companies and industry or professional associations have created more than 300 discrete certifications since 1989. Approximately 1.6 million individuals had earned about 2.4 million IT certificates by early 2000, most since 1997. Students outside the United States earned about half of the certificates. To earn a certificate, a candidate must pass an exam administered by a third party. A large industry has arisen to prepare candidates for these exams. This industry includes organizations that provide courses, tutorials, practice exams, self-study books, and CD-ROMs. Although some traditional four-year colleges and community colleges prepare students for these certification exams, much of the industry that supports IT certification is outside higher education as traditionally defined.

IT in Instruction

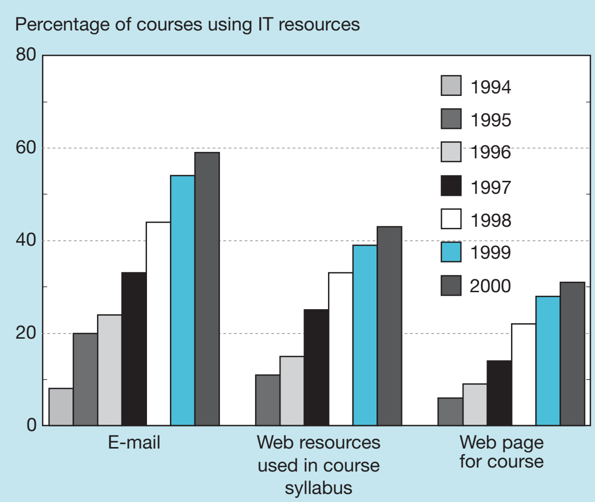
The Campus Computing Project (2000) found that IT use in college courses is increasing. There are indications that IT use is leveling off; nevertheless, e-mail, the Internet, and course Web pages are being used in more courses every year. (See figure 8-25.)

In some cases, decisions about IT use are left to individual professors. However, some universities (such as the University of California, Los Angeles) have required professors to establish Web pages for each course and to put syllabuses online. Support for the increased use of IT on college campuses has not been universal. Many professors and administrators enthusiastically embrace new technologies, and others prefer to wait for other institutions to find out which new technologies are useful in improving the quality of education.

Much of the new IT being used in scholarly communication and research can be used in instruction as well. Students can use on-line scholarly literature, participate in on-line scientific experiments, and learn from computer modeling and simulation. The future is likely to bring many additional IT applications in instruction.

Kulik (forthcoming) reviewed 44 studies from the 1990s on the effects of instructional technology in college courses. The studies focused on five computer applications: computer algebra systems, computer use (tutoring, simulations, and animations) in science, and computer-assisted language learning. In each study, instructional outcomes for students taught with and without computer help were compared. The instructional outcome measured most often in the studies was student learning. Kulik found that over the years, instructional technology has proven to be more and more effective in improving learning in college courses. Studies in the 1990s show a greater positive effect of instructional technology than stud-

Figure 8-25.
Use of technology in college instruction



SOURCE: Campus Computing Project. Available at <http://www.campuscomputing.net>.

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[10] IT in this discussion of patents consists of computers, peripherals, telecommunications, semiconductors, electronics, and software. Hicks et al.'s analysis covers patent activity between 1980 and 1999.

ies in the 1980s and earlier decades. The growing effectiveness of instructional technology coincides with the dramatic improvements in computing and with improvements in instructional software.

Although computer technologies are helping to improve student learning, they can also make it easier for students to cheat and plagiarize. The Internet contains many collections of school papers that students can download and use for their classes.

Distance Education

Distance education is not new. An estimated 100 million Americans have engaged in distance study, mostly correspondence courses, since 1890 (Distance Education and Training Council 1999), and in the 1960s there was widespread optimism about the use of television in education. IT is providing significant new tools for distance education. Many schools are either establishing distance education programs for the first time or expanding existing programs.

In on-line distance courses, the instructor typically e-mails "lectures" or posts them on a website, and students submit assignments and have "discussions" via e-mail. Courses often supplement textbooks with Web-based readings. Participants also may meet in a chat room at a certain time for on-line discussions. Courses also may have on-line bulletin boards or Web conferences, in which participants ask and respond to questions over time. In the not-too-distant future, as Internet bandwidths increase, video lectures and videoconferencing will become more common in on-line courses. Some courses may use more elaborate systems (so-called MUD/MOOs[11]) for group interaction, as well as groupware programs that involve simultaneous viewing of graphics and use of a shared writing space (e.g., white boards) (Kearsley 2000). Some courses may also use computer simulations over the Internet.

Distance education offers several potential advantages: it allows students to take courses that are not available locally; it allows students to balance coursework with their career and family life; and it can make education more available to people who are employed, especially those who are older and in midcareer or those who have family responsibilities. For universities, it offers a way to expand enrollment without increasing the size of the physical plant.

Although distance education traditionally is regarded as involving the delivery of courses to remote locations, the techniques of distance education, especially on-line education, can be incorporated in on-campus instruction as well. Universities are finding that significant numbers of on-campus students sign up for distance education courses when they are offered. At the University of Colorado in Denver, for example, more than 500 of 609 students enrolled in distance education courses were also enrolled in regular on-campus courses (Guernsey 1998). On-line courses can be more convenient for on-campus students, giving them greater flexibility in scheduling their time. Professors can augment their on-line courses with Web-based materials and guest lecturers in remote sites.

Distance Education Trends. The National Center for Education Statistics has conducted two surveys of distance education in postsecondary education institutions: the first in the fall of 1995 and the second in the 1997/98 academic year (National Center for Education Statistics (NCES) 1999b). The first survey covered only higher education institutions, but the second survey covered all postsecondary educational institutions. These surveys document that distance education is now a common feature of many higher education institutions, and its popularity is growing. The majority of courses are at the undergraduate level and are broadly distributed across academic subjects.

The number of higher education institutions offering distance education is growing. In 1997/98, 44 percent of all two- and four-year institutions offered distance education courses compared with 33 percent in fall 1995. Distance education is more widely used in public four-year institutions than in private four-year institutions, but private institutions are also increasing their use of it. In 1997/98, distance education was offered by 79 percent of public institutions (compared with 62 percent in fall 1995) and 22 percent of private institutions (compared with 12 percent in fall 1995).

Distance education course offerings and enrollments are growing more rapidly than the number of institutions that offer distance education. The number of courses offered in two- and four-year higher education institutions doubled from 25,730 in fall 1995 to 52,270 in 1997/98. The increases were fairly similar across all categories of institutions (two- and four-year, public and private, and all enrollment-size categories). Course enrollments also increased sharply, more than doubling from 753,640 in fall 1995 to 1,632,350 in 1997/98 (NCES 1999b).

The availability of degrees that can be completed exclusively with distance education courses has remained essentially constant. Of higher education institutions that offer distance education, 23 percent offered degrees in fall 1995 and 22 percent did so in 1997/98 (NCES 1999b).

Technologies used for distance education have changed significantly. In fall 1995, the most widely used technologies were two-way interactive video (57 percent) and one-way prerecorded video (52 percent). These were still widely used in 1997/98 (56 and 48 percent, respectively). Internet-based courses, however, expanded greatly. Of all the institutions that offered distance education courses in 1997/98, 60 percent offered asynchronous (not requiring student participation at a set time) computer-based instruction and 19 percent offered synchronous (real-time) computer-based instruction (NCES 1999b).

Significance of On-line Distance Education. Despite substantial (and growing) experience with on-line distance education, thorough assessments of its effectiveness have been relatively few. Existing evidence suggests that, at least in some circumstances, it can be very effective. The rapid growth and reported success of some on-line distance education programs indicate that they are providing acceptable learning experiences. A review of the literature on on-line classes (Kearsley, Lynch, and Wizer 1995) found that compared with traditional classes, student satisfaction was higher, measured student achievement

[11]MUD stands for multi-user domain or multi-user dungeon (reflecting its origins in games), and MOO stands for MUD, object-oriented.

was the same or better, and student-instructor discussions usually were more frequent. On the other hand, some case studies document that on-line distance education can be frustrating for both students and instructors. The growth of on-line distance education has far-reaching implications for higher education. Although on-line education may expand the pool of people who have access to education, it may also take students away from traditional education. Some scholars express concern that it will undermine the traditional college experience. Some question whether it can match the quality of face-to-face instruction. Moreover, the kind of intellectual and social community that characterizes the college experience may be much harder to achieve through distance learning.

IT Issues for Universities

IT in general and distance education in particular raise new issues for universities. Distance education brings universities into competition with each other in a new way. Because distance education courses are available to anyone anywhere, they allow universities to compete for students outside their own geographic areas. Top-tier universities such as Stanford and Duke are marketing Internet-based master's degrees to national audiences. New distance education–based universities such as Jones International University (<http://www.jonesinternational.edu>), the first on-line-only university to gain accreditation; the University of Phoenix on-line (<<http://online.uophx.edu>>); and Western Governors University (<http://www.wgu.edu>) are marketing courses that compete with the continuing education services of universities and colleges that in the past had been the only providers of such services in their regions. Some distance education providers see opportunities to market American university degrees to large student populations abroad. The reverse is also happening: the United Kingdom's Open University, which began providing distance education in the United Kingdom in 1971 and has established a good reputation there, has started an operation in the United States (Blumenstyk 1999a). In contrast to many institutions that are viewing Web-based course materials as a new source of revenue, MIT announced in 2001 that it would make nearly all of its course materials available for free on the Web over the next ten years (Massachusetts Institute of Technology, 2001).

In addition, distance education is creating new markets for companies that sell print materials and software to assist in on-line courses (Blumenstyk 1999b). Publishers such as McGraw-Hill and software companies such as Microsoft and Oracle have developed and are marketing on-line courses (Morris 1999). These commercial on-line courses represent another potential source of competition for universities, especially in preparing students for IT credentialing.

Distance education technologies also raise questions about the role of professors. Some view these technologies as new tools for professors. Others, however, foresee "mass production" education in which packaged multimedia courses will reduce the importance of professors (Noble 1998). The expanding and potentially lucrative new market for on-line course materials raises the issue of whether professors or the university should own the intellectual property embodied in on-line courses. The American Association of University Professors has taken the position that professors rather than institutions should retain primary property rights for on-line course materials (Schneider 1999) and has questioned the accreditation of Jones International University (Olson 1999).

Brown and Duguid (2000) note that colleges and universities provide three essential functions to learners: access to an authentic community of learning, resources to help learners work within these communities, and widely accepted representations of learning and work (such as degrees and transcripts). Brown and Duguid also note that many proposals for new "virtual universities" fail to provide one or more of these functions. Conventional universities serve all of these functions by combining five elements: students, faculty, research, facilities, and an institution able to provide an accepted degree. Brown and Duguid suggest that these elements will remain but that new technologies will allow the elements to be in a looser configuration, not necessarily combined in a single collocated organization.

The IT Workforce

During the 1996–2000 period, the rapid expansion of IT development and application during a period of full employment in the overall economy led to concerns about the availability of IT workers. In 2001, however, the cooling of the economy (especially in the IT sector) has, at least temporarily, ameliorated these concerns.

The Bureau of Labor Statistics has projected the future demand for IT workers (U.S. DOC 1997, 1999b, 2000c) for six core occupational classifications: computer engineers, systems analysts, computer programmers, database administrators, computer specialists, and all other computer scientists. These projections indicate that between 1998 and 2008, the United States will require more than 2 million new workers in these six occupations.

One indicator of the supply of IT workers is the number of computer science degrees awarded. After increasing sharply in the early 1980s, that number declined sharply after 1986 and has only begun to increase again since 1996. (See chapter 2, "Higher Education in Science and Engineering.")

The IT industry asserted that a serious shortage of IT workers exists, and many companies in various industries indicated that they needed more IT-trained workers to meet the growing demand. However, the existence of a shortage of IT workers was the subject of debate. Some employee groups believed there were enough trained technical professionals but that industry had not tapped existing labor pools (especially older engineers). The debate has been especially polarized over the issue of whether to allow more foreign workers with technical training to enter the country on temporary H-1B visas.

Several studies have examined the IT workforce issue (CSTB 2001; Freeman and Aspray 1999; Johnson and Bobo 1998; Lerman 1998; U.S. DOC 1999b). (See also chapter 3, "Science and Engineering Workforce.") These studies generally reached the following conclusions:

- **During 1996–2000, the IT labor market was somewhat tighter than the overall labor market.** Existing data, however, cannot prove or disprove that such a shortage existed. Federal data are limited by untimely reporting, out-of-date occupational descriptions, and incompatibilities in supply-and-demand data collected by different agencies.
- **The IT labor market is not homogeneous.** Supply-and-demand characteristics vary by region, industry segment, and specific skill. Because IT product cycle times are very fast, the industry pays a premium for people who already have specific current skills and do not require training to be effective. Competition is especially intense for people with specific "hot" skills in specific markets.
- **People enter IT careers in a variety of ways.** IT workers include people who majored in IT-related disciplines at the associate, bachelor's, master's, and doctoral degree levels; people from other science, engineering, and business fields; and people from nontechnical disciplines who have taken some courses in IT subjects. Many IT workers enter the field through continuing education programs and for-profit schools. Workers are taking advantage of new modes of instruction delivery such as distance learning.

Labor markets tend to be cyclical. In response to the tight conditions in the IT labor market during 1996–2000, wage increases attracted more people to the field, and many initiatives around the country were set up to help expand the IT workforce. Slower growth and even layoffs in the IT industry have also reduced demand for IT workers.

Conclusion

IT continues to develop rapidly as the key underlying technologies of semiconductors, disk drives, and network communications improve at exponential rates. Constant improvements in the underlying technologies make possible new IT applications that affect all areas of society, including the economy, households, government, and the R&D enterprise.

Throughout society, the utility of IT applications tends to advance much more slowly than the underlying technologies. A doubling of processing speeds, for example, does not bring a doubling of utility. The effective implementation and use of IT are the result of a complex process that requires not only adoption of a technology but also changes in organizations and institutions. As part of this process, individuals and organizations actively adapt (and sometimes resist) the technologies. As a result, the effects of IT on society often take place more slowly than visionaries predict. Nevertheless, the effects—driven by the continual change in underlying technologies—are substantial over time.

Selected Bibliography

Adelman, C. 2000. *A Parallel Postsecondary Universe: The Certification System in Information Technology.* Washington, DC: U.S. Department of Education.

Alberts, D.S., and D.S. Papp, eds. 1997. *The Information Age: An Anthology on Its Impact and Consequences*. Washington, DC: National Defense University.

Allen, T., and M.S. Morton, eds. 1994. *Information Technology and the Corporation of the 1990s.* New York: Oxford University Press.

Alpar, P., and M. Kim. 1991. "A Microeconomic Approach to the Measurement of Information Technology Value." *Journal of Management Information Systems* 7(2): 55–69.

Ante, S.E., with A. Borrus and R.D. Hof. 2001. "In Search of the Net's Next Big Thing." *Business Week* (March 26): 141.

Atkinson, R.D., and R.H. Court. 1998. *The New Economy Index: Understanding America's Economic Transformation.* Washington, DC: Progressive Policy Institute.

Attewell, P., and J. Rule. 1994. "Computing and Organizations: What We Know and What We Don't Know." In C. Huff and T. Finholt, eds., *Social Issues in Computing.* New York: McGraw-Hill.

Autor, D., L. Katz, and A. Krueger. 1997. "Computing Inequality: Have Computers Changed the Labor Market?" NBER Working Paper No. 5956. Cambridge, MA: National Bureau of Economic Research.

Baily, M.N., and A.K. Chakrabarti. 1988. *Innovation and the Productivity Crisis.* Washington, DC: Brookings Institution Press.

Baker, E.L., M. Gearhart, and J.L. Herman. 1994. "Evaluating the Apple Classrooms of Tomorrow." In E.L. Baker and H.F. O'Neil, Jr., eds., *Technology Assessment in Education and Training.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Banker, R.D., R.J. Kauffman, and M.A. Mahmood. 1993. *Strategic Information Technology Management: Perspectives on Organizational Growth and Competitive Advantage.* Harrisburg, PA: Idea Group Publishing.

Berman, E., J. Bound, and Z. Griliches. 1994. "Changes in the Demand for Skilled Labor Within U.S. Manufacturing: Evidence From the Annual Survey of Manufacturers." *Quarterly Journal of Economics* 109(May): 367–98.

Berman, H.M., J. Westbrook, Z. Feng, G. Gilliland, T.N. Bhat, H. Weissig, I.N. Shindyalov, and P.E. Bourne. 2000. "The Protein Data Bank." *Nucleic Acids Research* 28(1): 235–42. Available at <http://nar.oupjournals.org/cgi/content/full/28/1/235>.

Biemiller, L. 1999. "California State U. Adopts New Model to Pay for Journals." *Chronicle of Higher Education* July 16: A26.

Blumenstyk, G. 1999a. "Distance Learning at the Open University." *Chronicle of Higher Education* July 23: A35.

———. 1999b. "The Marketing Intensifies in Distance Learning." *Chronicle of Higher Education* April 9: A27.

Bradley, S.P., J.A. Hausman, and R.L. Nolan. 1993. *Globalization, Technology, and Competition: The Fusion of Computers and Telecommunications in the 1990s.* Boston: Harvard Business School Press.

Bresnahan, T. 1986. "Measuring the Spillovers From Technical Advance: Mainframe Computers in Financial Services." *American Economic Review* 76(4): 742–55.

———. (August) 1997. "Computerization and Wage Dispersion: An Analytical Reinterpretation." Paper prepared for the National Bureau of Economic Research, Summer Institute.

Brown, A.S. 1999. "Role Models." *Mechanical Engineering-CIME* 121(7): 44.

Brown, D. 2001. "Free Access to Medical Journals to be Given to Poor Countries." *The Washington Post.* July 9: A12.

Brown, J.S., and P. Duguid. 2000. *The Social Life of Information.* Boston: Harvard Business School Press.

Brunnel, D. 2000. *Making the Cisco Connection: The Story Behind the Real Internet Superpower.* New York: John Wiley.

Brynjolfsson, E. (December) 1993. "The Productivity Paradox of Information Technology: Review and Assessment." *Communications of the ACM* 36(12). Available at <http://ccs.mit.edu/papers/CCSWP130/ccswp130.html>. Accessed September 17, 2001.

Brynjolfsson, E., and L.M. Hitt. 1995. "Information Technology as a Factor of Production: The Role of Differences Among Firms." *Economics of Innovation and New Technology.* Special issue on information technology and productivity paradox. 3(4): 183–200.

———. 1996. "Paradox Lost? Firm-Level Evidence on the Returns to Information Systems Spending." *Management Science* 42(4): 541–58.

———. (August) 1998. "Beyond the Productivity Paradox." *Communications of the ACM.* Available at <http://ccs.mit.edu/erik/bpp.pdf>. Accessed September 17, 2001.

———. (April) 2000. "Computing Productivity: Firm-Level Evidence." Working paper. Available at <http://ebusiness.mit.edu/erik/cp.pdf>.

Brynjolfsson, E., and S. Yang. 1996. "Information Technology and Productivity: A Review of the Literature." *Advances in Computers* 43: 179–214. Available at <http://ebusiness.mit.edu/erik/itp.pdf>. Accessed September 17, 2001.

Bush, V. 1945. "As We May Think." *Atlantic Monthly.* Available at <http://www.theatlantic.com/unbound/flashbks/computer/bushf.htm>. Accessed August 4, 1999.

Campus Computing Project. 2000. "2000 National Survey of Information Technology in Higher Education." Available at <http://www.campuscomputing.net/>. Accessed September 17, 2001.

Casson, M. 1994. "Economic Perspectives on Business Information." In *Information Acumen: the Understanding and Use of Knowledge in Modern Business,* pp. 136–67. London: Routledge.

Castells, M. 1996. *The Rise of the Network Society.* Cambridge, MA: Basil Blackwell.

Center for Research in Electronic Commerce. 1999. "Internet Economy Indicators." Available at <http://www.internetindicators.com>. Accessed August 29, 1999.

Cerf, V.G. 1997. "Computer Networking: Global Infrastructure for the 21st Century." In *Computing Research Association, Computing Research: Driving Information Technology and the Information Industry Forward.* Available at <http://www.cs.washington.edu/homes/lazowska/cra/networks.html>.

Chandra, J., S.T. March, S. Mukherjee, W. Pape, R. Ramesh, H.R. Rao, and R.O. Waddoups. 2000. "Information Systems Frontiers." *Communications of the ACM* 43: 71–79.

Childers, T. 1975. *The Information-Poor in America.* Metuchen, NJ: Scarecrow Press.

Clemente, P.C. 1998. *State of the Net: The New Frontier.* New York: McGraw-Hill.

Committee on Issues in the Transborder Flow of Scientific Data, National Research Council. 1997. *Bits of Power: Issues in Global Access to Scientific Data.* Washington, DC: National Academy Press.

Computer Science and Telecommunications Board (CSTB). 1993. *National Collaboratories: Applying Information Technology for Scientific Research.* Washington, DC: National Academy Press.

———. 1994a. *Information Technology in the Service Society.* Washington, DC: National Academy Press.

———. 1994b. *Realizing the Information Future: The Internet and Beyond.* Washington, DC: National Academy Press.

———. 1997. *More Than Screen Deep: Toward Every Citizen Interfaces to the Nation's Information Infrastructure.* Washington, DC: National Academy Press.

———. 1998. *Fostering Research on the Economic and Social Impacts of Information Technology.* Washington, DC: National Academy Press.

———. 1999. *Funding a Revolution: Computer Support for Computing Research.* Washington, DC: National Academy Press. Available at <http://www.nap.edu/catalog/6323.html>.

———. 2001. *Building a Workforce for the Information Economy*. Washington, DC: National Academy Press.

Costa, A., and R. Liebmann, eds. 1997. *Supporting the Spirit of Learning: When Process Is Content.* Thousand Oaks, CA: Corwin Press.

Council of Economic Advisers. 2001. *Economic Report of the President Together with the Annual Report of the Council of Economic Advisers.* Washington, DC: U.S. Government Printing Office. Available at <http://w3.access.gpo.gov/eop/>.

Cron, W.L., and M.G. Sobol. 1983. "The Relationship Between Computerization and Performance: A Strategy for Maximizing the Benefits of Computerization." *Information and Management* 6: 171–81.

Cuban, L. 1994. "The Promise of the Computer." In C. Huff and T. Finholt, eds., *Social Issues in Computing.* New York: McGraw-Hill.

Cyert, R., and D. Mowery, eds. 1987. *Technology and Employment: Innovation and Growth in the U.S. Economy.* Washington, DC: National Academy Press.

Danziger, J.N., and K.L. Kraemer. 1986. *People and Computers: The Impacts of Computing on End Users in Organizations.* New York: Columbia University Press.

David, P.A. 1989. *Computer and Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror.* Stanford, CA: Stanford University, Center for Economic Policy Research.

Dewett, T., and G.R. Jones. 2001. "The Role of Information Technology in the Organization: A Review, Model, and Assessment." *Journal of Management* 27: 313–46.

Dickerson, M.D., and J.W. Gentry. 1983. "Characteristics of Adopters and Non-Adopters of Home Computers." *Journal of Consumer Research* 10: 225–35.

Distance Education and Training Council. 1999. "What is the DETC?" Available at <http://www.detc.org/>. Accessed August 23, 1999.

Downes, L., C. Mui, and N. Negroponte. 1998. *Unleashing the Killer App: Digital Strategies for Market Dominance.* Cambridge, MA: Harvard Business School Press. Available at <http://www.killer-apps.com>.

Drucker, P.F. 1999. "Beyond the Information Revolution." Atlantic Monthly 284 (4/October): 47–57.

Dutton, W.H., E.M. Rogers, and S.H. Jun. 1987. "The Diffusion and Impacts of Information Technology in Households." In P.I. Zorkoczy, ed*., Oxford Surveys in Information Technology,* p. 4. Oxford, England: Oxford University Press.

eBay. 2001. Company overview. Available at <http://pages.ebay.com/ community/aboutebay/overview/index.html>. Accessed April 17, 2001.

Educational Testing Service (ETS). 1997. *Computers and Classrooms: The Status of Technology in U.S. Schools, Policy Information Report.* Princeton: Educational Testing Service, Policy Information Center.

Egger, O., and M. Rauterberg. 1996. "Internet Behaviour and Addiction." Available at <http://www.ifap.bepr.ethz.ch/~egger/ibq/res.htm>. Accessed April 12, 1999.

ETAN Expert Working Group. (September) 1999. *Transforming European Science through Information and Communication Technologies: Challenges and Opportunities of the Digital Age.* Report prepared for the European Commission, Directorate General for Research. Available at <ftp://ftp.cordis.lu/pub/etan/docs/ict-report.pdf>.

Fine, C.H., and D.M.G. Raff. 2001. "Automotive Industry: Internet-Driven Innovation and Economic Performance." In Litan, R.E. and A.M. Rivlin eds. *The Economic Payoff from the Internet Revolution*. Washington: Brookings Institution Press, pp. 62–86.

Finholt, T.A. 2001. "Collaboratories." In B. Cronin, ed*., Annual Review of Information Science and Technology.* Available at <http://intel.si.umich.edu/crew/Technical%20reports/Finholt_Collaboratories_10_06_00.pdf>.

Forester, T. 1989. *Computers in the Human Context: Information Technology, Productivity, and People.* Cambridge, MA: MIT Press.

Forrester Research. 1998. "U.S. On-line Business Trade Will Soar To $1.3 Trillion By 2003, According To Forrester Research." News release. Available at <http://www.forrester.com>. Accessed August 29, 1999.

———. (September 28) 1999. "Online Retail To Reach $184 Billion By 2004 As Post-Web Retail Era Unfolds." News release. Available at <http://www.forrester.com/ER/Press/Release/0,1769,164,FF.html>. Accessed September 17, 2001.

Fountain, J.E. 2001a. *Building the Virtual State: Information Technology and Institutional Change.* Washington, DC: Brookings Institution Press.

———. 2001b. "Digital Government: A View from the States." Working paper. Harvard University, John F. Kennedy School of Government, Taubman Center for State and Local Government.

Fountain, J.E., with C. Osorio-Urzua. 2001. "The Economic Impact of the Internet on the Government Sector." In Litan, R.E. and A.M. Rivlin eds. *The Economic Payoff from the Internet Revolution.* Washington, DC: Brookings Institution Press.

Fox, S., and L. Rainie. 2000. "The On-line Health Care Revolution: How the Web Helps Americans Take Better Care of Themselves." Available at <http://www. pewinternet.org/reports/toc.asp?Report=26>. Accessed September 17, 2001.

Freeman, C., L. Soete, and U. Efendioglu. 1995. "Diffusion and the Employment Effects of Information and Communication Technology." *International Labor Review* 134(4–5): 587–603.

Freeman, P., and W. Aspray. 1999. *The Supply of Information Technology Workers in the United States.* Washington, DC: Computing Research Association.

Friedlander, A. 1997. *Infrastructure: The Utility of Past as Prologue.* Reston, VA: Corporation for National Research Initiatives.

Friedlander, A., and R.S. Bessette. (January 31) 2001. "The Implications of Information Technology For Scientific Publishing: A Literature Review." Draft report prepared for the Division of Science Resources Studies, Directorate for Social, Behavioral, and Economic Sciences, National Science Foundation. With contributions by J.R. Cooper and R. Love, Esq.

Getz, M. 1997. "Electronic Publishing in Academia: An Economic Perspective." Paper presented at the Scholarly Communication and Technology Conference, Emory University, Atlanta, GA, April 24–25, 1997. Available at <http://arl.cni.org/scomm/scat/getz.html>. Accessed August 18, 1999.

Giacquinta, J.B., J. Bauer, and J.E. Levin. 1993. *Beyond Technology's Promise: An Examination of Children's Educational Computing at Home.* Cambridge, England: Cambridge University Press.

Glanz, J. 2001a. “Web Archive Opens a New Realm of Research.” *New York Times* (on-line) May 1. Available (for fee) at <http://www.nytimes.com>.

———. 2001b. “The Web as Dictator of Scientific Fashion.” *New York Times* (on-line) June 19. Available (for fee) at <http://www.nytimes.com>.

Gomery, R.E. 1994. “A Ricardo Model with Economies of Scale.” *Journal of Economic Theory* 62(April): 394–419.

Graham, J. 1976. *Making Computers Pay.* New York: John Wiley and Sons.

Greenspan, A. 1999. “High-Tech Industry in the U.S. Economy.” Testimony presented before the Joint Economic Committee, U.S. Congress. Available at <http://www.federalreserve.gov/boarddocs/testimony/1999/19990614.htm>.

Griliches, Z. 1997. “Comment on Sichel ‘The Productivity Slowdown: Is a Growing Unmeasurable Sector the Culprit?’” *Review of Economics and Statistics* 79(3/August): 371.

Guernsey, L. 1998. “Distance Education for the Not-So-Distant.” *Chronicle of Higher Education* March 27: A29.

Gulliksen, J.E. 2000. “MST vs. MEMS: Where Are We?” *Semiconductor Technology* 1 (10/October). Available at <http://www.semi.org/web/wmagazine.nsf/>.

Gurstein, P. 1991. “Working at Home and Living at Home: Emerging Scenarios.” *Journal of Architectural and Planning Research* 8(2): 164–80.

Hicks, D., T. Breitzman, D. Olivastro, and K. Hamilton. 2001. “The Changing Composition of Innovative Activity in the US—a Portrait Based on Patent Analysis.” *Research Policy* 30: 681–703.

Hoffman, D., and T. Novak. 1998. “Bridging the Digital Divide: The Impact of Race on Computer Access and Internet Use.” Available at <http://www2000.ogsm.vanderbilt.edu/papers/race/science.html>. Accessed April 12, 1999.

Hollingsworth, P. 1999. “Web Technology Forces Innovation.” *Food Technology* 53 (11): 36.

Howell, D., and E. Wolff. 1993. “Changes in the Information-Intensity of the U.S. Workplace Since 1950: Has Information Technology Made a Difference?” Monograph R.R. #93–08. New York: New York University, C.V. Starr Center for Applied Economics.

Huff, C., and T. Finholt, eds. 1994. *Social Issues in Computing.* New York: McGraw-Hill.

International Data Corporation. 1999. “Internet Commerce Will Rocket to More Than $1 Trillion by 2003.” Press release. Available at <http://www.idc.com/Press/default.htm>. Accessed August 29 1999.

International Technology Roadmap for Semiconductors. 2000. “ITRS 2000 Updates.” Available at <http://public.itrs.net/Files/2000UpdateFinal/2kUdFinal.htm>. Accessed July 9, 2001.

Internet Policy Institute. 2001. “Report of the National Workshop on Internet Voting: Issues and Research Agenda.” Available at <http:www.netvoting.org>. Accessed September 17, 2001.

Johannessen, J.A., J. Olaisen, and B. Olsen. 2001. “Mismanagement of Tacit Knowledge: The Importance of Tacit Knowledge, the Danger or Information Technology, and What To Do About It.” *International Journal of Information Management* 21: 3–20.

Johnson, G.E., and F.P. Stafford. 1998. “Technology Regimes and the Distribution of Real Wages.” In G. Eliasson and C. Green, eds*., Microfoundations of Economic Growth: A Schumpeterian Perspective.* Ann Arbor, MI: University of Michigan Press.

Johnson, S.T., and J.A. Bobo. 1998. *Software Workers for the New Millennium: Global Competitiveness Hangs in the Balance.* Arlington, VA: National Software Alliance.

JSTOR. 1999. “About JSTOR.” Available at <http://www.jstor.org/about/>. Accessed August 24, 1999.

Kahin, B., and C. Nesson. 1997. *Borders in Cyberspace.* Cambridge, MA: MIT Press.

Kahn, R.E., and V.G. Cerf. 1999. “What Is The Internet (And What Makes It Work)?” Available at <http://www.internetpolicy.org/briefing/12_99_story.html>. Accessed September 17, 2001.

Katz, J.E., and P. Aspden. 1997. “A Nation of Strangers?” *Communications of the ACM* 40(12): 81–86.

Katz, L.F. 2000. “Technological Change, Computerization, and the Wage Structure.” In E. Brynjolfsson and B. Kahin, eds. *Understanding the Digital Economy.* Cambridge, MA: MIT Press.

Kearsley, G. 2000. “Learning and Teaching in Cyberspace” (version 5/00) Available at <http://home.sprynet.com/~gkearsley/chapts.htm>

Kearsley, G., W. Lynch, and D. Wizer. 1995. “Effectiveness and Impact of Computer Conferencing in Graduate Education.” *Educational Technology* 35, 37–42.

Kenney, M., and J. Curry. 2000. “We All Want to be Like Mike: The Internet and the Personal Computer Value Chain.” Paper prepared for the workshop on E-Commerce and the Changing Terms of Competition: A View from Within the Sectors, April 28–29, 2000, Berkeley, CA. Available at <http://e-conomy.berkeley.edu/ conferences/9-2000/EC-conference2000_papers/KENNEYpcandinternet.pdf>.

Khosrowpour, M. 1994. *Information Technology and Organizations: Challenges of New Technologies.* Harrisburg, PA: Idea Group Publishing.

Kiernan, V. 1999. “Why Do Some Electronic-Only Journals Struggle, While Others Flourish?” *Chronicle of Higher Education* May 21: A25.

Kling, R. 2000. “Learning about Information Technologies and Social Change: The Contribution of Social Informatics.” *The Information Society* 16(3/July–September): 217–32. Available at <http://www.slis.indiana.edu/TIS/articles/ kling16(3).pdf>.

Kling, R., and R. Lamb. 1999. "IT and Organizational Change in Digital Economies: A Socio-Technical Approach." Paper prepared for the conference on Understanding the Digital Economy: Data, Tools and Research, Washington, DC, May 25–26, 1999. Available at <http://mitpress.mit.edu/ude.html>. In E. Brynjolfsson and B. Kahin, eds., *Understanding the Digital Economy.* Cambridge, MA: MIT Press.

Kling, R., and G. McKim. 1999. "Scholarly Communication and the Continuum of Electronic Publishing." *Journal of the American Society for Information Science and Technology* 50(10): 890–906. Available at <http://xxx.lanl.gov/ftp/cs/papers/9903/9903015.pdf>.

Kling, R., and G. McKim. 2000. "Not Just a Matter of Time: Field Differences and the Shaping of Electronic in Supporting Scientific Communication." *Journal of the American Society for Information Science and Technology* 51(14): 1306–20. Available at <http://xxx.lanl.gov/ftp/cs/papers/9909/9909008.pdf>.

Konrad, R., and D. Kawamoto. 2001. "Assessing the Carnage: A Year After the Net Bubble Burst, Blame Game Begins." *CNET News Com.* 8 (March 8). Available at <http://news.cnet.com/news/0-1007-201-4948893-0.html>. Accessed September 17, 2001.

Kranzberg, M. 1989. "IT as Revolution." In T. Forester, ed., *Computers in the Human Context: Information Technology, Productivity, and People.* Cambridge, MA: MIT Press.

Kraut, R., V. Lundmark, M. Patterson, S. Kiesler, T. Mukopadhyay, and W. Scherlis. 1998a. "Internet Paradox: A Social Technology That Reduces Social Involvement and Psychological Well-Being?" *American Psychologist* 53(9): 1017–31.

Kraut, R., T. Mukhopadhyay, J. Szczypula, S. Kiesler, and W. Scherlis. 1998b. "Communication and Information: Alternative Uses of the Internet in Households." In *CHI '98, Proceedings of the 1998 Conference on Human Factors in Computing Systems, Association for Computing Machinery Special Interest Group on Computer-Human Interaction.* Los Angeles, CA: Association for Computing Machinery.

Kraut, R., W. Scherlis, T. Mukhopadhyay, J. Manning, and S. Kiesler. 1996. "The HomeNet Field Trial of Residential Internet Services." *Communications of the ACM* 39(12): 55–63.

Kulik, C.L., and J.A. Kulik. 1991. "Effectiveness of Computer-Based Instruction: An Updated Analysis." *Computers in Human Behavior* 7: 75–94.

Kulik, J.A. Forthcoming. "Effectiveness of Instructional Technology." In *Colleges and Universities: What Does the Research Say?*

Kurzweil, R. 2001. "The Singularity is Near—A Book PrÈcis." Available at <http://www.kurzweilai.net/articles/art0134.html?printable=1>. Accessed July 2, 2001.

Kyrillidou, M. 2000. *ARL Supplementary Statistics 1998–99.* Washington, DC: Association of Research Libraries.

Landauer, T.K. 1995. *The Trouble With Computers: Usefulness, Usability, and Productivity.* Cambridge, MA: MIT Press.

Landefeld, J.S., and B.M. Fraumeni. 2001. "Measuring the New Economy." *Survey of Current Business* March: 23–40. Available at <http://www.bea.doc.gov/bea/articles/beawide/2001/0301mne.pdf >. Accessed September 17, 2001.

Lawrence, S., and L. Giles. 1999. "Accessibility of Information on the Web." *Nature* 400 (July 8): 107–09.

Leiner, B., M. Vinton, G. Cerf, D.D. Clark, R.E. Kahn, L. Kleinrock, D.C. Lynch, J. Postel, L.G. Roberts, and S. Wolff. 1998. "A Brief History of the Internet." Available at <http://www.isoc.org/internet/history/brief.html>.

Lenhart, A. 2001. *Who's Not On-line: 57% of Those Without Internet Access Say They Do Not Plan To Log On.* Washington, DC: Pew Internet and American Life Project. Available at <http://www.pewinternet.org/reports/toc/asp?Report=21>. Accessed September 17, 2001.

Lerman, R.I. 1998. "Emerging Trends in the Information Technology Job Market: How Should the Public and Private Sectors Respond?" Testimony presented before the Subcommittee on Oversight and Investigations Committee on Education and the Workforce, U.S. House of Representatives. Available at <http://www.urban.org/TESTIMON/lerman4-23-98.html>.

Lerner, J., and J. Tirole. 2001. "The Open Source Movement: Key Research Questions." *European Economic Review* 45: 819–26.

Lesk, M. 1997a. "How Much Information Is There in the World?" Available at <http://www.lesk.com/mlesk/ksg97/ksg.html>. Accessed August 5, 1999.

———. 1997b. *Practical Digital Libraries: Books, Bytes, and Bucks.* San Francisco: Morgan Kauffman.

Lewis, T. 2000. "Corporate R&D in the Age of E-Commerce." *Research Technology Management* 42 (6/November–December): 16–20.

Library of Congress. 2001. "Fascinating Facts About the Library of Congress." Available at <http://www.loc.gov/today/fascinate.html#STATS>. Accessed April 17, 2001.

Lichtenberg, F.R. 1995. "The Output Contributions of Computer Equipment and Personnel: A Firm-Level Analysis." *Economics of Innovation and New Technology* 3: 201–17.

Link, A.N., and J.T. Scott. 1998. "Assessing the Infra-Structural Needs of a Technology-Based Service Sector: A New Approach to Technology Policy Planning." *STI Review* 22 (August).

Litan, R.E., and A.M. Rivlin. 2001. "The Economy and the Internet: What Lies Ahead?" In Litan, R.E., and A.M. Rivlin, eds. *The Economic Payoff from the Internet Revolution,* pp. 1–28. Washington, DC: Brookings Institution Press.

Lyman, P., and H.R. Varian. 2000. "How Much Information?" Available at <http://www.sims.berkeley.edu/how-much-info>. Accessed July 2, 2001.

Machlup, F. 1962. *The Production and Distribution of Knowledge in the United States.* Princeton: Princeton University Press.

Machovec, G. 1997. "Electronic Journal Market Overview—1997." Available at <http://www.coalliance.org/reports/ejournal.htm>. Accessed September 17, 2001.

Mann, D., C. Shakeshaft, J. Becker, and R. Kottkamp. 1999. *West Virginia's Basic Skills/Computer Education Program: An Analysis of Student Achievement.* Santa Monica, CA: Milken Family Foundation.

Marshall, E. 1999. "E-biomed Morphs to E-biosci: Focus Shifts to Reviewed Papers." *Science* 285(August 6): 810–11.

Massachusetts Institute of Technology. 2001. "MIT to make nearly all course materials available free on the World Wide Web." Press release. Available at <http://web.mit.edu/newsoffice/nr/2001/ocw.html>. Accessed October 2, 2001.

McQuarrie, E.F. 1989. "The Impact of a Discontinuous Innovation: Outcomes Experienced by Owners of Home Computers." *Computers in Human Behavior* 5: 227–40.

Mesenbourg, T. 2001. "Measuring the Digital Economy". Paper presented at the Netcentric Economy Symposium, University of Maryland, March 30, 2001. Available at <https://www.rhsmith.umd.edu/dit/lucas/ditsymp/papers/mesenbourg.pdf>. Accessed September 14, 2001.

Metcalfe, R. 1996. "The Internet After the Fad." Remarks of Dr. Robert Metcalfe at the University of Virginia. May 30, 1996. Available at <http://www.americanhistory.si.edu/csr/comphist/montic/metcalfe.htm#me7>. Accessed September 17, 2001.

Miller, G.E., n.d. "An Interview with Frank Mayadas of the Alfred P. Sloan Foundation." *American Journal of Distance Education* 11(3). Available at <http://www.aln.org/alnweb/mayadas_miller.htm>.

Minar, N., and M. Hedlund. 2001. "A Network of Peers: Peer-to-Peer Models Through the History of the Internet." In A. Oram, ed., *Peer-to-Peer: Harnessing the Power of Disruptive Technologies,* Chapter 1. Available at <http://www.oreilly.com/catalog/peertopeer/chapter/ch01.htm>.

Mogge, D. 1999. "Seven Years of Tracking Electronic Publishing: The ARL Directory of Electronic Journals, Newsletters, and Academic Discussion Lists." *Library Hi Tech* 17(1): 17–25.

Mogge, D., and P. Budka. 2000. *The Directory of Scholarly Electronic Journals and Academic Discussion Lists.* Washington, DC: Association of Research Libraries.

Monaghan, P. 1998. "U. of Washington Professors Decry Governor's Visions for Technology." *Chronicle of Higher Education* June 19: A23.

Moore, G. 1999. "Gordon Moore on Moore's Law." Available at <http://developer.intel.com/update/archive/issue2/feature.htm>. Accessed August 20, 1999.

Morisi, T.L. 1996. "Commercial Banking Transformed by Computer Technology." *Monthly Labor Review* 119(8/August): 30–36.

Morris, K. 1999. "Wiring the Ivory Tower." *Business Week* August 9: 90–92.

Moye, W.T. 1996. "ENIAC: The Army-Sponsored Revolution." ARL Historian. Available at <http://ftp.arl.mil/~mike/comphist/96summary/>. Accessed August 4, 1999.

Nagarajan, A., J.L. Bander, and C.C. White. 1999. "Trucking." In Board on Science, Technology, and Economic Policy, National Research Council, *U.S. Industry in 2000: Studies in Competitive Performance,* pp. 123–54. Washington, DC: National Academy Press.

Napster. 2001. Press releases. Available at <http://www.napster.com/pressroom/ pr/20Million.html>; <http://www.napster.com/pressroom/pr/001031.html>; <http://www.napster.com/pressroom/pr/010327.html>. Accessed September 17, 2001.

National Automated Clearing House Association. (April 12) 1999. "Electronic Payments in 1998 Surpass 5.3 Billion, Up 17.5% Over Year Ago." Press release. Available at <http://www.nacha.org/news/news/pressreleases/1999/PR041299–03/pr041299–03.htm>. Accessed September 16, 1999.

National Center for Education Statistics (NCES). 1999a. *Internet Access in Public Schools and Classrooms: 1994–98.* Washington, DC: U.S. Department of Education. Available at <http://www.nced.ed.gov/pubsearch/pubsinfo.asp?pubid=1999017>.

———. 1999b. *Distance Education at Postsecondary Education Institutions: 1997–98.* Washington, DC: U.S. Department of Education (NCES 200–013).

National Coordination Office for Computing, Information, and Communications. 2000. *Information Technology Frontiers for a New Millennium.* Available at <http://www.itrd.gov/pubs/blue00/asci.html>. Accessed September 17, 2001.

National Information Infrastructure Advisory Council. 1995. *A Nation of Opportunity: A Final Report of the United States Advisory Council on the National Information Infrastructure.* Available at <http://www.benton.org/Library/KickStart/ nation.home.html>. Accessed September 17, 2001.

National Science and Technology Council. 2000. *National Nanotechnology Initiative: The Initiative and its Implementation Plan.* Report to the Committee on Technology, Subcommittee on Nanoscale Science, Engineering and Technology. Washington, DC. Available at <http://www.nano.gov/>.

National Science and Technology Council, Subcommittee on Computing, Information, and Communications R&D, Committee on Technology. 1999. *High Performance Computing and Communications: Information Technology Frontiers for a New Millennium.* Available at <http://www.ccic.gov/pubs/blue00/>. Accessed September 17, 2001.

National Science Foundation. 2001a. *The Application and Implications of Information Technologies in the Home: Where are the Data and What Do They Say?* Arlington, VA: National Science Foundation, Division of Science Resources Studies. Available at <http://www.nsf.gov/sbe/srs/nsf01313/exec.htm>.

———. 2001b. "NEES—A Major Research Equipment Project of the National Science Foundation (NSF)." Available at <http://www.eng.nsf.gov/nees/>. Accessed September 17, 2001.

————. 2001c. "Distributed Terascale Facility to Commence with $53 Million NSF Award." NSF Press release.

Available at <http://www.nsf.gov/od/lpa/news/press/01/pr0167.htm>. Accessed October 2, 2001.

———. Forthcoming. *IT at Work: What We Know About the Impacts of IT-Mediated Remote Working on Employment and Work in the U.S.* March 2001 Draft report. Arlington, VA: National Science Foundation, Division of Science Resources Studies.

National Venture Capital Association. (January 29) 2001. "Venture Capital Investments Achieve Record Levels in 2000, Torid Pace Relaxed in Fourth Quarter." News release. Available at <http://www.nvca.org/VEpress01_29_01.htm>. Accessed September 17, 2001.

Noble, D.F. 1998. "Digital Diploma Mills: The Automation of Higher Education." *First Monday* 3(1). Available at <http://www.firstmonday.dk/issues/ issue3_1/noble/index.html#author>. Accessed September 17, 2001.

Noyelle, T., ed. 1990. *Skills, Wages, and Productivity in the Service Sector.* Boulder, CO: Westview Press.

Odlyzko, A. 1997. "The Economics of Internet Journals." *First Monday* 2(8). Available at <http://www.firstmonday.dk/issues/issue2_8/odlyzko/index.html>. Accessed September 17, 2001.

Office of Technology Assessment (OTA). 1995. *Teachers and Technology: Making the Connection.* Washington, DC: U.S. Government Printing Office.

Office of Technology Policy. 1997. *America's New Deficit: The Shortage of Information Technology Workers.* Washington, DC: U.S. Department of Commerce.

———. (January) 1998. *Update: America's New Deficit.* Washington, DC: U.S. Department of Commerce.

Ogburn, W.F. 1964. *On Culture and Social Change: Selected Papers.* O.D. Duncan, ed. Chicago: University of Chicago Press.

Oliner, S.D., and D. Sichel. 1994. "Computers and Output Growth Revisited: How Big Is the Puzzle?" *Brookings Papers on Economic Activity* 2: 273–315.

Olson, F. 1999. "Virtual Institutions Challenge Accreditors to Devise New Ways of Measuring Quality." *Chronicle of Higher Education* August 6: A29.

Olson, G.M., and J.S. Olson. 2001. "Distance Matters." *Human Computer Interaction* 15: 139–79. Available at <http://intel.si.umich.edu/crew/Technical%20reports/Olson_Olson_distance_ matters_10_23_00.pdf>. Accessed September 17, 2001.

Online Computer Library Center (OCLC). 1999. "June Web Statistics." Available at <http://wcp.oclc.org/>. Accessed September 17, 2001.

Optoelectronics Industry Development Association. 2001. "How DWDM Spurs Bit Rates" *OIDA News* 10(3/September):3. Available at <http://www.oida.org/oidanews901.pdf >. Accessed October 2, 2001.

Organisation for Economic Co-operation and Development (OECD). 1998a. *The Global Research Village: How Information and Communication Technologies Affect the Science System*. Paris. Available at <http://www.oecd.org/dsti/sti/s_t/scs/prod/on-line.htm>.

———. 1998b. *Information Technology Outlook 1997.* Paris.

———. 1999a. *Communications Outlook 1999.* Paris.

———. 1999b. *The Economic and Social Impact of Electronic Commerce.* Paris.

———. 1999c. "The Knowledge-Based Economy: A Set of Facts and Figures." Paper presented at the meeting of the Committee for Scientific and Technological Policy at Ministerial Level. Paris, June 22–23.

———. 2000a. *Cellular Mobile Price Structure and Trends.* Paris.

———. 2000b. *Local Access Pricing and E-Commerce.* Paris.

———. 2001a. *Measuring the ICT Sector.* Paris. Available at <http://www.oecd.org/dsti/sti/it/prod/measuring_ict.htm>.

———. 2001b. *Understanding the Digital Divide.* Paris. Available at <http://www.oecd.org/dsti/sti/prod/Digital_divide.pdf>.

Papert, S. 1995. "Technology in Schools: Local Fix or Global Transformation?" Testimony presented before a U.S. House of Representatives Panel on Technology and Education. Available at <http://kids.www.media.mit.edu/projects/kids/sp-talk.html>.

Pew Internet American Life Project. 2000. *Tracking Online Life: How Women Use the Internet to Cultivate Relationships with Family and Friends.* Washington, DC. Available at <http://www.pewinternet.org/reports/pdfs/Report1.pdf>. Accessed September 17, 2001.

President's Committee of Advisors on Science and Technology (PCAST), Panel on Educational Technology. 1997. "Report to the President on the Use of Technology to Strengthen K–12 Education in the United States." Available at <http://www.ostp.gov/PCAST/k-12ed.html>. Accessed September 17, 2001.

President's Information Technology Advisory Committee. 2001. *Digital Libraries: Universal Access to Human Knowledge.* Available at <http://www.itrd.gov/pubs/pitac/pitac-dl-9feb01.pdf>. Accessed September 17, 2001.

Quinn, J.B. 2000. "Outsourcing Innovation: The New Engine of Growth." *Sloan Management Review* 41(4/Summer): 13–28.

Regalado, A. 1999. "Mining the Genome." *Technology Review* 102(5/September–October): 56–63.

Riccobono, J.A. 1986. *Use of Electronic Information Technologies for Non-School Learning in American Households: Report of Findings From the 1985 Home Information Technology Study (HITS).* CS–86–215. Washington, DC: U.S. Department of Education, Center for Statistics.

Robinson, J.P., K. Barth, and A. Kohut. 1997. "Social Impact Research: Personal Computers, Mass Media, and Use of Time." *Social Science Computer Review* 15 (1): 65–82.

Rosenberg, R. 1997. *The Social Impact of Computers.* 2nd ed. San Diego: Academic Press.

Ross-Flanigan, N. 1998. "The Virtues (and Vices) of Virtual Colleagues." *Technology Review* 101(2/March–April): 52–60.

Schneider, A. 1999. "AAUP Seeks Greater Faculty Role in Distance-Learning Decisions." *Chronicle of Higher Edu-*

cation June 25: A34.

Science. 1996. “Computers in Biology. ” Special issue on the role of computers in biological research and knowledge accumulation. 273(August 2): 585–607.

Shirky, C. 2000. “What Is P2P…And What Isn’t.” The O’Reilly Network. Available at <http://www.openp2p.com/pub/a/p2p/2000/11/24/shirky1-whatisp2p.html>. Accessed September 17, 2001.

Sichel, D. 1997. *The Computer Revolution: An Economic Perspective.* Washington, DC: Brookings Institution.

Sinclair, B. 1999. “Sequence of Die: Automated Instrumentation for the Genome Era.” *The Scientist* 13(8): 18. Available at <http://www.the-scientist.com/yr1999/apr/profile1_990412.html>.

Solow, R. 1987. “Technological Change and the Aggregate Production Function.” *Review of Economics and Statistics* 39(August): 312–20.

———. 1987. “We’d Better Watch Out.” *New York Times* book review. July 12: 36.

Stoll, C. 1995. *Silicon Snake Oil: Second Thoughts on the Information Highway.* New York: Doubleday.

Tapscott, D. 1996. *The Digital Economy: Promise and Peril in the Age of Networked Intelligence.* New York: McGraw-Hill.

Teasley, S., and S. Wolinsky. 2001. “Scientific Collaborations at a Distance.” *Science* 292(June 22): 2254–55.

Thompson, M.J. (April 16) 2001. “B-to-B-ing Optimistic.” *Industry Standard*. Available at <http://www.thestandard.com/ article/ 0,1902,23670,00.html>. Accessed April 17, 2001.

Thurow, L. 1987. “Economic Paradigms and Slow American Productivity Growth.” *Eastern Economic Journal* 13: 333–43.

Turkle, S. 1984. *The Second Self: Computers and the Human Spirit.* New York: Simon and Schuster.

———. 1995. *Life on the Screen: Identity in the Age of the Internet.* New York: Simon and Schuster.

U.S. Census Bureau. 2001a. “Retail E-Commerce Sales in Second Quarter 2001 were $7.5 Billion, Up 24.7 Percent From Second Quarter 2000, Census Bureau Reports. Washington, DC: U.S. Department of Commerce. October 15. Available at <http://www.census.gov/mrts/www/current.html>.

———. 2001b. “E-commerce 1999.” *E-Stats*. Washington, DC: U.S. Department of Commerce. March 7. Available at <http://www.census.gov/ estats>.

———. 2001c. “Manufacturing 1999 and mid-2000.” *E-Stats*. Washington, DC: U.S. Department of Commerce. June 8. Available at <http://www.census.gov/estats>.

U.S. Department of Commerce (DOC). 1997. *America’s New Deficit: The Shortage of Information Technology Workers.* Washington, DC.

———. 1999a. *The Emerging Digital Economy II.* Washington, DC. Available at <http://www.ecommerce.gov>.

———. 1999b. *The Digital Work Force: Building Infotech Skills at the Speed of Innovation.* Washington, DC. Available at <http://www.ta.doc.gov/reports/itsw/ Digital.pdf>.

U.S. Department of Commerce, Economics and Statistics Administration. 2000a. *Digital Economy 2000.* Washington, DC.

U.S. Department of Commerce. 2000b. *Falling Through The Net: Toward Digital Inclusion. A Report on Americans’ Access to Technology Tools.* Washington, DC.

U.S. Department of Commerce. 2000c. *Update: The Digital Workforce.* Washington, DC.

U.S. Department of Energy (DOE). 2001. *Accelerated Strategic Computing Initiative Program Plan.* Washington, DC. Available at <http://www.lanl.gov/programs/nwsc/DOCS/01-ASCI-Prog-001_scr1.pdf>. Accessed September 14, 2001.

U.S. Department of Energy/National Science Foundation (DOE/NSF). 1998. National Workshop on Advanced Scientific Computing. July 30–31.

U.S. Library of Congress. 1999. *Report on Copyright and Digital Distance Education.* Report of the Register of Copyrights. Washington, DC.

U.S. Working Group on Electronic Commerce. 2000. *Leadership for the New Millennium, Delivering on Digital Progress and Prosperity.* 3rd annual report, 2000. Washington, DC: U.S. Government Printing Office.

Varmus, H. 1998. “New Directions in Biology and Medicine.” Plenary lecture at the annual meeting of the American Association for the Advancement of Science. Philadelphia, February 13, 1998. Available at <http://www.nih.gov/welcome/director/ 021398.htm>.

———. 1999. “Fiscal Year 2000 President’s Budget Request for the National Institutes of Health.” Statement made before the House and Senate Appropriations Subcommittees on Labor, Health and Human Services, and Education. Available at <http://www.nih.gov/welcome/director/022299.htm>.

Vitalari, N.P., A. Venkatesh, and K. Gronhaug. 1985. “Computing in the Home: Shifts in the Time Allocation Patterns of Households.” *Communications of the ACM* 28(5): 512–22.

Walsh, J.P., and N.G. Maloney. 2001. “Computer Network Use, Collaboration Structures and Productivity.” Available at <http://tigger.uic.edu/~jwalsh/Collab.html>. Accessed July 16, 2001. Forthcoming in P. Hinds and S. Kieler, eds., *Distributed Work,* Cambridge, MA: MIT Press.

Webster, F. 1997. “What Information Society?” In D.S. Alberts and D.S. Papp, eds., *The Information Age: An Anthology on Its Impact and Consequences*. Available at <http://www.ndu.edu/ndu/inss/books/Anthology1/part1.html>.

Welch, D. 2001. “Can Covisint Climb Out of a Ditch?” *BusinessWeek* May 21: 128B–D.

Williams, M.E. 1985. “Electronic Databases” *Science* 228(4698/April 26): 445–50, 455–56.

Wilson, E.J. III. 2000. “Closing the Digital Divide: An Initial Review.” Washington, DC: Internet Policy Institute. Available at <http://www.internetpolicy.org/briefing/ErnestWilson0700.html>. Accessed September 17, 2001.

Wong, R., and R. Jesty. 2001. "The Wireless Internet: Applications, Technology and Market Strategies." Available at <http://www.allnetdevices.com/wireless/opinions/2001/01/10/the_wireless.html>. Accessed September 17, 2001.

World Information Technology and Services Alliance. 1999. *Digital Planet: The Global Information Economy.* Arlington, VA: WITSA.

Wrolstad, J. 2001. "Rising Tide for Wireless Internet." *Wireless NewsFactor* (February 23). Available at <http://www.wirelessnewsfactor.com/perl/story/7718.html>. Accessed September 17, 2001.

Young, J.R. 1998. "600 Colleges and Universities to Gain Access to a Huge Data Base." *Chronicle of Higher Education* July 3: A20.